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ABSTRACT

Otoliths commonly are used to determine the taxon, age, and size of fishes. This information is useful for population management, predator-prey studies, and archaeological research. The relationship between the length of a fish and the length of its otoliths remains unknown for many species of marine fishes in the Pacific Ocean. Therefore, the relationships between fish length and fish weight, and between otolith length and fish length, were developed for 63 species of fishes caught in the eastern North Pacific Ocean. We also summarized similar relationships for 46 eastern North Pacific fish species reported in the literature. The relationship between fish length and otolith length was linear, and most of the variability was explained by a simple least-squares regression ($r^2 > 0.700$ for 45 of 63 species). The relationship between otolith length and fish length was not significantly different between left and right otoliths for all but one fish species. Images of otoliths from 77 taxa are included to assist in the identification of species.

Introduction

All bony fishes (Osteichthyes) have three pairs of otoliths (earbones or earstones): the sagittae, asteriscus, and lapillus. These otoliths are composed of calcium carbonate in the form of aragonite, in a protein matrix. They are contained within membranous labyrinths in paired otic capsules on either side of the skull. The sagittae are the largest pair of otoliths in most bony fishes; however, in minnows (Cypriniformes) and catfish (Siluriformes) the asterici are the largest (Hecht, 1977). Fisheries biologists have used sagittae to determine age and growth of fishes because of the large size and distinct growth rings of sagittae (Chilton and Beamish, 1982; Boehlert, 1985; Summerfelt and Hall, 1987).

Because otoliths are dense they can withstand some degree of dissolution, and often species can be recognized by the distinctive morphology of the sagittae (Morrow, 1979; Smale et al., 1995). Paleontologists have identified otoliths in middens (Fitch, 1969), oceanographers have determined species of fishes from otoliths in sediments (Fitch, 1964, 1968), and prey have been identified using otoliths collected from stomachs of piscivorous fishes (Trippel and Beamish, 1987), marine

birds (Ainley et al., 1981), and marine mammals (Fitch and Brownell, 1968; Treacy and Crawford, 1981). Fishes eaten by pinnipeds also were identified using otoliths found in feces (Bailey and Ainley, 1982; Brown and Mate, 1983; Antonelis et al., 1984; Harvey, 1987).

Trout (1954) and Templemann and Squires (1956) were among the first to demonstrate a significant positive relationship between otolith size and fish size of Barents Sea cod (*Boreogadus saida*) and haddock (*Melanogrammus aeglefinus*). Otolith length also has been correlated with fish weight (Casteel, 1976). Since these early studies, relationships between otolith length and fish length have been determined for some species, including North Pacific gadids (Frost and Lowry, 1981), rock-fishes (*Sebastodes* spp.; Wyllie Echeverria, 1987), and several fishes off Baja California, Mexico (Gamboa, 1991).

For most species, the relationship between otolith length and fish length can be described by a simple linear regression. For North Pacific gadids, this relation-

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ship has been best described by two linear regressions with an inflection point (Frost and Lowry, 1981). Left and right sagittae also may differ in size within a rockfish species (Wyllie Echeverria, 1987), and sometimes otolith size is different among stocks of fishes, such as Atlantic herring (*Clupea harengus*; Messieh, 1972).

The objective of this study was to compile information regarding the relationship between otolith length and fish length for fish species of the eastern North Pacific Ocean using original collections and published and unpublished literature. These data may be used by researchers studying archaeology and food habits of piscivores to determine the size of fishes from the length of recovered otoliths. We also wanted to provide images of most fish otoliths, for which we had regressions, to be used as an aid for identifying species of fish.

Methods

Fishes were collected throughout the eastern North Pacific Ocean (e.g. Bering Sea, Gulf of Alaska, and off Washington, Oregon, and California) using bottom and midwater trawls, beach seines, gill nets, and hook-and-line gear. Fish were weighed to the nearest 0.1 g on a Mettler balance (<600 g) and spring or pan scale (>600 g). Standard length (SL; most anterior point to the base of hypural plate at caudal flexion) or fork length (FL; most anterior point to the base of the fork in the caudal fin) was measured to the nearest millimeter.

Sagittae were removed, cleaned, and stored dry in vials. Lengths of sagittae were determined using handheld vernier calipers under a dissecting microscope. Sagittal otolith length was recorded as the greatest distance measured from the anterior rostrum to the posterior edge, parallel to the sulcus.

The relationship between otolith length and fish length (SL or FL) was determined using a least-squares linear regression. The appropriateness of the linear model was determined by plotting the residuals against the independent variable. Differences between regression coefficients for the relationship of fish length and the lengths of left and right otoliths were tested using *t* tests. When the equations for left and right otoliths did not differ statistically, one right or left otolith was selected randomly from each individual and a single linear regression reported for each fish species. The significance of the linear regression was tested using an analysis of variance (ANOVA). Relationships between otolith length and fish length for additional species were obtained from published and unpublished sources. Relationships between fish length and fish weight were determined using a least-squares regression of the log of fish weight and length (Ricker, 1975). Although transformation back to arithmetic units may

result in underestimating weight, these errors are usually small (Saila et al., 1988).

Results

Forty-six relationships between fish and otolith size previously reported in the literature involved various measures of fish length—fork length, total length (defined as the distance from the most anterior point to the most posterior point), and standard length measured in millimeters or centimeters—and otolith length (Table 1). Many of the published regressions of fish length to otolith length were developed for species common in food habit studies of marine mammals (Frost and Lowry, 1981; Brown and Mate, 1983) or species that were commercially important (Spratt, 1975; Boehlert and Yoklavich, 1984; Wyllie Echeverria, 1987).

Sixty-three species of fishes were collected in connection with the current study (Table 2). Most relationships between weight and length were described by a traditional allometric equation, where weight of a fish is approximately equal to length to the third power (Table 2). Linearized forms of this power relationship explained >90% of the variability in 43 of 60 cases. For three species, no weight data were collected. For 17 additional species, the sample size was less than 20; therefore, these weight/length relationships should be used with caution.

Generally the relationship between fish length and otolith length was linear, and most of the variability was explained by the regression ($r^2 > 0.700$ in 45 of 63 cases; Table 2). All relationships except one were significant ($P < 0.05$). There was no significant relationship between otolith length and fish length for *Trachurus symmetricus* (Table 2). Regression coefficients of otolith length to fish length were not significantly different for left and right otoliths, except for the wattled eelpout (*Lycodes palearis*; $P < 0.05$), however, the analysis was probably influenced by the small sample size ($n=12$). Size of fish should not be predicted from otolith size or fish weight for measurements outside the range used for the regressions.

To assist in the identification of recovered otoliths, we provide images of fish otoliths (Fig. 1) for most species sampled. These otoliths are listed according to taxonomic relationships (Robins et al., 1991). We chose otoliths that were representative of the species, and presented multiple images of otoliths from species where the otolith morphology changed with size.

Discussion

Otoliths have been used to identify fish species eaten by marine predators (Fitch and Brownell, 1968; Pitcher, 1980;

Table 1

Published relationships of fish otolith length (or mass) and fish length (or mass) for fishes in the eastern North Pacific. NA indicates data not available, and the codes for the variables (x and y) are defined at the bottom of the table.

Species	Regression	Variables	r^2	n	Location	Reference
<i>Bonogadus saida</i> (Arctic cod)	$y = 2.20x + 1.59$	b	0.98	202	Beaufort & Chukchi Seas	Frost and Lowry (1981)
<i>Citharichthys sordidus</i> (Pacific sanddab)	$y = 0.02x + 1.02$	a	0.93	46	Oregon	Brown and Mate (1983)
<i>Eleginops gracilis</i> (saffron cod)	$y = 2.32x - 4.84$	b, c	0.96	110	Bering & Chukchi Seas	Frost and Lowry (1981)
<i>Engraulis mordax</i> (northern anchovy)	$y = 1.74x - 0.09$	b, d	0.93	36		
<i>Erebus zachirus</i> (rex sole)	$y = 33.22x - 8.49$	e	0.88	121	California	Spratt (1975)
<i>Hippoglossus stenolepis</i> (Pacific halibut)	$y = 0.02x + 1.02$	a	0.98	78	Oregon	Brown & Mate (1983)
<i>Lepidotrigla armatus</i> (staghorn sculpin)	$\ln(y) = 1.31 \ln x - 1.32$	b	NA	2,503	North Pacific	Southward (1962)
<i>Lyopsetta exilis</i> (slender sole)	$\ln(y) = 1.97 \ln x + 6.00$		0.90	128	North Pacific	Southward and Chapman (1965)
<i>Microstomus pacificus</i> (dover sole)	$y = 0.02x + 0.30$	a	0.98	14	Oregon	Brown and Mate (1983)
<i>Oncopterus keta</i> (chum salmon)	$y = 0.02x + 0.62$	a	0.97	45	Oregon	Brown and Mate (1983)
<i>Oncorhynchus kisutch</i> (coho salmon)	$\log_{10}y = 1.23 + 3.21 \log_{10}x$	f	0.99	43	North Pacific	Casteel (1974)
<i>Oncorhynchus mykiss</i> (rainbow trout)	$\log_{10}y = 0.89 + 5.93 \log_{10}x$	f	0.99	19	North Pacific	Casteel (1974)
<i>Oncorhynchus nerka</i> (sockeye salmon)	$y = 0.006x + 2.16$	a	0.97	121	British Columbia, Washington, Oregon	McKem et al. (1974)
<i>Oncorhynchus tshawytscha</i> (chinook salmon)	$\log_{10}y = 0.29 + 4.13 \log_{10}x$	f	0.95	86	North Pacific	Casteel (1974)
<i>Pleuronectes vetulus</i> (English sole)	$\log_{10}y = 0.59 + 4.15 \log_{10}x$	f	0.99	53	North Pacific	Casteel (1974)
<i>Sebastodes auriculatus</i> (brown rockfish)	$y = 0.03x + 0.53$	a	0.99	81	Oregon	Brown and Mate (1983)
<i>Sebastodes australis</i> (aurora rockfish)	$y = 33.16x - 53.03$	g	0.94	78	California	Wyllie Echeverria (1987)
<i>Sebastodes carnatus</i> (gopher rockfish)	$y = 19.91x + 15.12$	g	0.61	71	California	Wyllie Echeverria (1987)
<i>Sebastodes ephippiatus</i> (copper rockfish)	$y = 30.57x - 39.37$	g	0.89	203	California	Wyllie Echeverria (1987)
<i>Sebastodes chlorostictus</i> (greenspotted rockfish)	$y = 30.23x + 5.10$	g	0.82	132	California	Wyllie Echeverria (1987)
<i>Sebastodes ahyponomeus</i> (black-and-yellow rockfish)	$y = 24.11x - 18.54$	g	0.95	174	California	Wyllie Echeverria (1987)
<i>Sebastodes edwardsii</i> (starry rockfish)	$y = 28.61x - 21.78$	g	0.84	166	California	Wyllie Echeverria (1987)
<i>Sebastodes errans</i> (darkblotched rockfish)	$y = 25.27x - 37.48$	g	0.96	99	California	Wyllie Echeverria (1987)
<i>Sebastodes fimbriatus</i> (splintnose rockfish)	$y = 28.10x - 27.10$	g	0.94	89	California	Wyllie Echeverria (1987)
<i>Sebastodes elongatus</i> (greenstriped rockfish)	$y = 22.64x - 12.85$	g	0.96	78	California	Wyllie Echeverria (1987)
<i>Sebastodes mento</i> (widow rockfish)	$y = 24.02x - 13.56$	g	0.95	98	California	Wyllie Echeverria (1987)
<i>Sebastodes nebulosus</i> (yellowtail rockfish)	$y = 33.11x - 6.89$	g	0.81	106	California	Wyllie Echeverria (1987)
<i>Sebastodes jordani</i> (shortbelly rockfish)	$y = 26.51x - 10.95$	g	0.88	184	California	Wyllie Echeverria (1987)
<i>Sebastodes goodeti</i> (chilipepper)	$y = 29.13x - 58.00$	g	0.96	78	California	Wyllie Echeverria (1987)
<i>Sebastodes aophinsii</i> (squarespot rockfish)	$y = 28.87x - 30.55$	g	0.92	59	California	Wyllie Echeverria (1987)
<i>Sebastodes jordani</i> (shortbelly rockfish)	$y = 22.10x - 2.31$	g	0.97	183	California	Wyllie Echeverria (1987)

Continued

Table 1 (continued)

Species	Regression	Variables	r^2	n	Location	Reference
<i>Sebastodes leucis</i> (cowcod)	$y = 47.46x - 170.11$	g	0.95	29	California	Wyllie Echeverria (1987)
<i>Sebastodes maliger</i> (quillback rockfish)	$y = 29.97x - 53.11$	g	0.86	34	California	Wyllie Echeverria (1987)
<i>Sebastodes melanops</i> (black rockfish)	$y = 30.56x - 48.22$	g	0.86	209	California	Wyllie Echeverria (1987)
<i>Sebastodes melanostomus</i> (blackgill rockfish)	$y = 30.56x - 47.07$	g	0.86	80	California	Wyllie Echeverria (1987)
<i>Sebastodes miniatus</i> (vermillion rockfish)	$y = 29.36x - 56.74$	g	0.93	99	California	Wyllie Echeverria (1987)
<i>Sebastodes mystinus</i> (blue rockfish)	$y = 29.77x - 18.18$	g	0.83	204	California	Wyllie Echeverria (1987)
<i>Sebastodes nebulosus</i> (China rockfish)	$y = 25.18x + 32.97$	g	0.79	48	California	Wyllie Echeverria (1987)
<i>Sebastodes ovalis</i> (speckled rockfish)	$y = 33.56x - 53.47$	g	0.91	84	California	Wyllie Echeverria (1987)
<i>Sebastodes pacificus</i> (bocaccio)	$y = 41.09x - 77.09$	g	0.82	86	California	Wyllie Echeverria (1987)
<i>Sebastodes prinneri</i> (canary rockfish)	$y = 29.41x - 85.11$	g	0.92	173	California	Wyllie Echeverria (1987)
<i>Sebastodes rosaceus</i> (rosy rockfish)	$y = 22.53x - 83.48$	g	0.81	147	California	Wyllie Echeverria (1987)
<i>Sebastodes ruberrimus</i> (yelloweye rockfish)	$y = 31.33x - 76.23$	g	0.92	102	California	Wyllie Echeverria (1987)
<i>Sebastodes saxicola</i> (striped rockfish)	$y = 23.40x - 32.77$	g	0.95	102	California	Wyllie Echeverria (1987)
<i>Sebastodes seminudus</i> (halfbanded rockfish)	$y = 25.27x - 19.18$	g	0.85	31	California	Wyllie Echeverria (1987)
<i>Sebastodes serranoides</i> (olive rockfish)	$y = 29.35x - 51.01$	g	0.93	130	California	Wyllie Echeverria (1987)
<i>Theragra chalcogramma</i> (walleye pollock)	$y = 3.18x - 9.77$	b, h	0.97	98	Bering Sea	Frost and Lowry (1981)
	$y = 2.25x - 0.51$	b, l	0.98	158		

a x = fish standard length (mm), y = otolith length (mm)

b x = otolith length (mm), y = fish fork length (cm)

c otolith length > 8.5 mm

d otolith length < 8.5 mm

e x = otolith length (mm), y = fish standard length (mm)

f x = otolith length (mm), y = fish weight (g)

g x = otolith length (mm), y = fish total length (mm)

h otolith length > 10.0 mm

i otolith length < 10.0 mm

Table 2

Relationships of fish weight (WT) in grams to fish standard length (SL) in centimeters, and standard length to length of otolith (OL) in millimeters. For each equation, the number of fish or otoliths measured (N), coefficient of determination (r^2), standard error of the regression coefficient (SE_β), and range of fish lengths is given. Species and common names from Robins et al. (1991).

Species (common name)	Location ¹	Fish weight/fish length			Fish length/otolith length			Range
		Equation	N	r^2	Equation	N	r^2	
<i>Allosmerus elongatus</i> (whitebait smelt)	OR	WT = 0.0063 SL ^{3.233}	25	0.893	SL = 2.11 (OL) + 3.02	23	0.838	7.9–9.7
<i>Alosa septimissima</i> (American shad)	OR	WT = 0.0135 SL ^{3.046}	7	0.997	SL = 11.46 (OL) – 11.08	14	0.960	8.4–37.1
<i>Ammodytes hexapterus</i> (Pacific sand lance)	CA	WT = 0.0063 SL ^{2.790}	10	0.913	SL = 4.06 (OL) + 2.01	10	0.433	9.3–13.6
<i>Anoplopoma fimbria</i> (sablefish)	AK	WT = 0.0163 SL ^{2.902}	74	0.993	SE $_\beta$ = 1.643			
<i>Atheresthes stomaia</i> (arrowtooth flounder)	OR	WT = 0.0093 FL ^{2.999}	101	0.961	SE $_\beta$ = 0.120			
<i>Atherinops affinis</i> (topsmelt)	CA	WT = 0.1698 SL ^{1.733}	14	0.429	FL = 4.75 (OL) + 1.62	94	0.955	9.3–46.7
<i>Atherinopsis californiensis</i> (jacksnelt)	CA	WT = 0.0049 SL ^{3.228}	12	0.968	SL = 3.72 (OL) + 0.55	84	0.925	31.1–37.5
<i>Bathymaster signatus</i> (searcher)	WA	WT = 0.0038 SL ^{3.256}	44	0.991	SE $_\beta$ = 0.325			
<i>Chilara taylori</i> (spotted cusk-eel)	CA	WT = 0.0004 SL ^{3.761}	22	0.964	SL = 4.85 (OL) – 2.46	18	0.950	4.1–14.1
<i>Chitonotus pugilensis</i> (roughback sculpin)	WA	WT = 0.0217 SL ^{2.871}	11	0.960	SE $_\beta$ = 0.279			
<i>Citharinichthys sordidus</i> (Pacific sanddab)	WA, OR	WT = 0.0352 SL ^{2.710}	60	0.851	SL = 3.48 (OL) + 1.90	43	0.883	11.8–31.5
<i>Clupea pallasi</i> (Pacific herring)	WA, OR	WT = 0.0044 SL ^{3.398}	83	0.976	SL = 2.51 (OL) + 2.15	29	0.730	11.4–25.2
<i>Coryphaenoides acrolepis</i> (Pacific rattail)	OR	WT = 0.0016 SL ^{3.299}	10	0.921	SE $_\beta$ = 0.294			
<i>Cymatogaster aggregata</i> (shiner perch)	OR, CA	WT = 0.0100 SL ^{3.515}	85	0.979	SL = 3.37 (OL) – 4.52	11	0.857	5.5–11.8
<i>Dasyatichthys setiger</i> (spinyhead sculpin)	GA	No data available			SE $_\beta$ = 0.460			
<i>Eleginops gracilis</i> (saffron cod)	GA	WT = 0.0039 SL ^{3.292}	13	0.990	SL = 2.87 (OL) + 3.29	61	0.727	3.3–25.5
<i>Embiotoca jacksoni</i> (black perch)	CA	WT = 0.0282 SL ^{3.148}	19	0.992	SE $_\beta$ = 0.229			
<i>Embiotoca lateralis</i> (striped seaperch)	OR, CA	WT = 0.0329 SL ^{3.043}	25	0.998	SL = 5.24 (OL) – 1.85	82	0.934	5.1–22.7
<i>Engraulis mordax</i> (northern anchovy)	CA	WT = 0.0485 SL ^{2.413}	34	0.807	SE $_\beta$ = 0.166			
<i>Eopsetta exilis</i> (slender sole)	GA	WT = 0.0058 SL ^{3.293}	50	0.974	SL = 3.44 (OL) – 3.23	10	0.926	19.0–36.0
					SE $_\beta$ = 0.368			
					SL = 1.74 (OL) – 0.52	90	0.925	4.8–12.2
					SE $_\beta$ = 0.053			
					FL = 3.11 (OL) – 7.03	49	0.655	8.0–33.0
					SE $_\beta$ = 0.368			
					SL = 1.89 (OL) – 2.76	46	0.960	9.2–20.9
					SE $_\beta$ = 0.058			
					SL = 2.45 (OL) – 2.61	52	0.947	5.2–18.4
					SE $_\beta$ = 0.082			
					SL = 2.90 (OL) – 5.68	25	0.990	6.6–26.4
					SE $_\beta$ = 0.061			
					SL = 2.28 (OL) + 0.85	56	0.694	3.6–14.4
					SE $_\beta$ = 0.206			
					SL = 3.37 (OL) + 1.08	50	0.771	8.0–20.5
					SE $_\beta$ = 0.265			

Continued

Table 2 (continued)

Species (common name)	Location ¹	Fish weight/fish length				Fish length/otolith length				Range
		Equation	N	r^2	Equation	N	r^2			
<i>Lophopsetta jordani</i> (petrale sole)	OR, CA	WT = 0.0086 SL ^{3.231}	17	0.986	SL = 4.85 (OL) - 4.81 $SE_{\beta} = 0.468$	20	0.857	13.7-37.0		
<i>Eryx zacatirus</i> (rex sole)	WA, OR	WT = 0.0238 SL ^{2.692}	67	0.932	SL = 4.80 (OL) - 2.50 $SE_{\beta} = 0.226$	70	0.869	12.0-29.7		
<i>Gadus macrocephalus</i> (Pacific cod)	BS	No data available			FL = 4.51 (OL) - 22.97 $SE_{\beta} = 0.226$	110	0.883	10.0-106.0		
<i>Genyonemus lineatus</i> (white croaker)	CA	WT = 0.0550 SL ^{2.700}	40	0.767	SL = 1.52 (OL) + 4.66 $SE_{\beta} = 0.209$	48	0.534	9.1-28.0		
<i>Gymnoanthus gradeatus</i> (armorhead sculpin)	BS	WT = 0.0100 SL ^{3.196}	29	0.939	SL = 1.75 (OL) + 0.82 $SE_{\beta} = 0.360$	28	0.476	7.3-15.0		
<i>Hippoglossoides elassodon</i> (flathead sole)	WA	WT = 0.0078 FL ^{3.041}	99	0.984	FL = 4.63 (OL) - 0.71 $SE_{\beta} = 0.063$	40	0.947	17.2-30.5		
<i>Hyperoplus argenteum</i> (walleye surferch)	OR, CA	WT = 0.0116 SL ^{3.361}	23	0.996	SL = 2.57 (OL) - 2.83 $SE_{\beta} = 0.543$	24	0.987	5.6-20.7		
<i>Hypomesus pretiosus</i> (surf smelt)	OR	WT = 0.0044 SL ^{3.345}	42	0.986	SL = 3.61 (OL) - 0.63 $SE_{\beta} = 0.204$	25	0.932	6.9-15.4		
<i>Hypsopsetta guttulata</i> (diamond turbot)	CA	WT = 0.0853 SL ^{2.664}	14	0.967	SL = 4.89 (OL) - 0.29 $SE_{\beta} = 0.543$	18	0.835	7.1-26.9		
<i>Leptocottus armatus</i> (Pacific staghorn sculpin)	WA, OR, CA	WT = 0.0111 SL ^{3.229}	51	0.990	SL = 2.58 (OL) - 2.26 $SE_{\beta} = 0.092$	62	0.928	3.7-22.5		
<i>Lycodes brevipes</i> (shortfin eelpout)	BS	WT = 0.0195 FL ^{2.522}	56	0.826	FL = 3.47 (OL) + 4.83 $SE_{\beta} = 0.430$	62	0.520	18.5-27.6		
<i>Lycodes cortezaeanus</i> (bigfin eelpout)	WA, CA	WT = 0.0018 SL ^{3.245}	40	0.993	SL = 10.96 (OL) - 21.82 $SE_{\beta} = 1.773$	41	0.742	11.5-44.7		
<i>Lycodes palearis</i> (wattled eelpout)	BS	WT = 0.0007 FL ^{3.383}	25	0.913	FL = 5.22 (OL) + 12.42 $SE_{\beta} = 3.82$	24	0.283	32.0-47.0		
<i>Lycodopsis pacifica</i> (blackbelly eelpout)	GA	WT = 0.0018 SL ^{3.302}	22	0.954	SL = 3.82 (OL) + 4.89 $SE_{\beta} = 0.719$	20	0.610	14.4-23.3		
<i>Mallotus villosus</i> (capelin)	BS	WT = 0.0054 SL ^{3.160}	39	0.717	SL = 3.45 (OL) + 3.62 $SE_{\beta} = 0.417$	39	0.649	10.0-13.7		
<i>Merluccius productus</i> (Pacific hake)	OR	WT = 0.0081 SL ^{2.966}	75	0.933	SL = 2.04 (OL) + 0.96 $SE_{\beta} = 0.078$	86	0.891	26.3-54.4		
<i>Microgadus proximus</i> (Pacific tomcod)	WA, OR	WT = 0.0064 SL ^{3.191}	80	0.988	SL = 1.77 (OL) - 3.51 $SE_{\beta} = 0.048$	101	0.932	6.1-28.3		
<i>Microstomus pacificus</i> (Dover sole)	OR	WT = 0.0094 SL ^{3.092}	101	0.854	SL = 3.72 (OL) + 6.97 $SE_{\beta} = 0.301$	117	0.587	7.6-37.8		
<i>Oncorhynchus kisutch</i> (coho salmon)	OR	WT = 0.0103 SL ^{3.092}	43	0.989	SL = 16.31 (OL) - 40.74 $SE_{\beta} = 2.138$	46	0.569	12.5-58.4		
<i>Oncorhynchus mykiss</i> (rainbow trout)	OR	WT = 0.0275 SL ^{2.895}	18	0.905	SL = 16.28 (OL) - 38.14 $SE_{\beta} = 1.381$	39	0.790	12.0-26.1		
<i>Ophiodon elongatus</i> (lingcod)	OR, CA	WT = 0.0023 SL ^{3.567}	10	0.620	SL = 8.23 (OL) - 8.20 $SE_{\beta} = 0.315$	35	0.722	5.3-71.9		
<i>Osmerus mordax</i> (rainbow smelt)	BS	WT = 0.0038 SL ^{3.278}	32	0.819	SL = 2.69 (OL) + 0.32 $SE_{\beta} = 0.292$	29	0.759	13.0-17.9		

Continued

Table 2 (continued)

Species (common name)	Location ¹	Fish weight/fish length			Fish length/otolith length			
		Equation	N	r ²	Equation	N	r ²	
<i>Phanerodon furatus</i> (white seaperch)	OR, CA	WT = 0.0213 SL ^{3.086}	17	0.997	SL = 2.33 (OL) - 21.5 SE _β = 0.109	46	0.912	4.5–23.5
<i>Platichthys stellatus</i> (starry flounder)	OR, CA	WT = 0.0107 SL ^{3.268}	25	0.985	SL = 3.35 (OL) + 0.23 SE _β = 0.303	30	0.814	8.2–37.3
<i>Pleuragrammus monopterygius</i> (Atka mackerel)	BS	WT = 0.0034 FL ^{3.401}	16	0.987	FL = 8.40 (OL) - 4.99 SL = 2.17 (OL) + 10.65	13	0.864	19.0–35.0
	BS	WT = 0.0024 SL ^{3.605}	7	0.859	FL = 6.16 (OL) - 6.97 SL = 3.82 (OL) - 2.76	26	0.638	22.7–30.7
<i>Pleuronectes bilineatus</i> (rock sole)	BS	WT = 0.0112 FL ^{2.997}	83	0.931	SE _β = 0.059	29	0.841	7.3–32.0
<i>Pleuronectes vetulus</i> (English sole)	WA, OR, CA	WT = 0.0163 SL ^{2.339}	98	0.995	SE _β = 0.059	151	0.965	3.5–36.1
<i>Podothecus acipenserinus</i> (sturgeon poacher)	BS, WA, OR	WT = 0.0030 SL ^{3.233}	93	0.956	SL = 6.58 (OL) - 6.21 SE _β = 0.303	92	0.840	7.3–25.7
<i>Porichthys notatus</i> (plainfin midshipman)	WA, OR, CA	WT = 0.0207 SL ^{2.916}	78	0.967	SL = 2.80 (OL) - 2.59 SE _β = 0.090	80	0.926	4.0–26.6
<i>Psettiichthys melanostictus</i> (sand sole)	WA, OR, CA	WT = 0.0052 SL ^{3.441}	25	0.983	SL = 5.06 (OL) - 3.18 SE _β = 0.256	26	0.942	8.1–31.0
<i>Rhachichthys vacca</i> (pile perch)	WA, OR	WT = 0.0182 SL ^{3.218}	46	0.997	SL = 3.35 (OL) - 8.19 SE _β = 0.098	45	0.965	6.2–33.5
<i>Sebastodes melanops</i> (black rockfish)	OR	WT = 0.1225 SL ^{2.499}	21	0.585	SL = 2.23 (OL) - 1.48 SE _β = 0.181	53	0.749	12.2–42.0
<i>Sebastodes paucispinis</i> (bocaccio)	OR	No data available			SL = 2.41 (OL) + 0.14 SE _β = 0.398	13	0.769	8.4–41.8
<i>Sebastolobus alascanus</i> (shortspine thornyhead)	OR	WT = 0.0102 SL ^{3.239}	69	0.988	SL = 2.31 (OL) - 3.71 SE _β = 0.150	51	0.828	15.1–49.2
<i>Sebastolobus altivelis</i> (longspine thornyhead)	OR	WT = 0.0155 SL ^{3.113}	13	0.997	SL = 4.94 (OL) - 27.50 SE _β = 0.652	13	0.839	15.8–55.5
<i>Spirinchus thaleichthys</i> (longfin smelt)	OR	WT = 0.0288 SL ^{2.531}	50	0.854	SL = 2.64 (OL) - 0.20 SE _β = 0.142	50	0.878	7.3–11.6
<i>Synaphurus atricauda</i> (California tonguefish)	CA	WT = 0.0074 SL ^{3.136}	32	0.789	SL = 3.56 (OL) + 4.64 SE _β = 0.563	48	0.464	6.5–15.2
<i>Thaleichthys pacificus</i> (enlachon)	OR	WT = 0.0077 SL ^{3.075}	129	0.884	SL = 4.71 (OL) - 2.70 SE _β = 0.181	102	0.871	10.5–19.8
<i>Theragra chalcogramma</i> (walleye pollock)	WA	WT = 0.0043 SL ^{3.255}	46	0.985	SL = 2.24 (OL) - 2.35 SE _β = 0.081	44	0.948	12.6–43.2
<i>Trachurus symmetricus</i> (jack mackerel)	OR, CA	WT = 0.0635 SL ^{2.556}	18	0.761	Not significant	14	0.141	25.5–33.3
<i>Trichodon trichodon</i> (Pacific sandfish)	BS	WT = 0.0170 FL ^{2.553}	19	0.971	FL = 6.06 (OL) - 4.57 SL = 1.88 (OL) - 0.07 SE _β = 0.079	17	0.684	15.0–25.0
<i>Zalemius rosaceus</i> (pink seaperch)	CA	WT = 0.0199 SL ^{3.102}	48	0.841	SE _β = 0.079	56	0.912	7.0–12.8

¹ Location of capture: BS = Bering Sea, CA = California, GA = Gulf of Alaska, OR = Oregon, WA = Washington.

Brown and Mate, 1983; Harvey, 1987). Specific guides or keys to fish otoliths also have been published (Morrow, 1979; Harkonen, 1986; Hecht, 1987; Smale et al., 1995).

Generally, standard length of fishes is linearly related to otolith length. Predicting size of fishes (length and weight) can be accomplished with fair reliability on the basis of otolith length. This relationship, however, is not always reliable. Otolith length typically is linearly related to length of the fish until the fish reaches maximum size; thereafter, the otolith increases only in thickness (Blacker, 1974; Williams and Bedford, 1974). Otolith lengths of larval and juvenile fishes may increase in a curvilinear fashion relative to fish length for some species, such as sockeye salmon (*Oncorhynchus nerka*; West and Larkin, 1987) and walleye pollock (*Theragra chalcogramma*; Nishimura and Yamada, 1988). The relationship between otolith length and fish length may be dependent on the growth rate of the fish, as was reported for striped bass (*Morone saxatilis*; Secor and Dean, 1989). Additionally, the relationship between otolith length and fish length may be described by multiple linear lines with inflection points (e.g. gadids; Frost and Lowry, 1981). Multiple linear relationships may result from different growth stanzas (Laidig et al., 1991). These results indicate that size of fish should only be estimated over the size distribution sampled, and that all length intervals should be sampled properly with the appropriate statistical model.

Estimating size of consumed fishes from measurements of otoliths recovered in stomachs or feces may be biased because of partial or complete digestion of otoliths (Jobling and Breiby, 1986; Jobling, 1987). For instance, size of fish eaten by the harbor seal (*Phoca vitulina*) may be underestimated by 16–44% (Harvey, 1989). Similar results have been reported for many pinnipeds (Hawes, 1983; da Silva and Neilson, 1985; Murie and Lavigne, 1986). Although a rough estimate of these errors may be obtained from controlled experiments, the amount of digestion may be species-specific, requiring numerous tests to document all forms of bias. There also may be differences between the sexes in the relationship between fish size and otolith size, something we did not test. Researchers using otoliths to determine number and size of fish eaten, therefore, should realize the limitations of this technique.

Fish size-otolith size relationships will be useful for researchers examining food habits of piscivores and size of fish in archaeological samples. Many more species and sizes of fish should be sampled to cover the full range of fishes involved in these studies.

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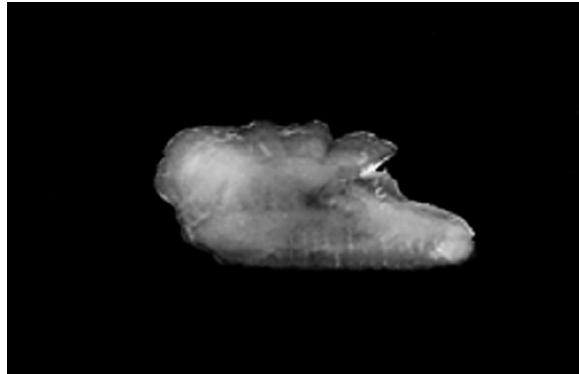
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Figure 1

Otolith images of 76 species of fishes from the eastern North Pacific, listed in taxonomic order (Robins et al., 1991). For species with extreme variability in otolith morphology, multiple images are provided. For each species, the scientific and common names, position and size of the otolith pictured, and length and mass of the fish from which the otolith was removed are given. The regression relationships between (1) weight (WT in grams) and fish length (SL in cm) and (2) fish length (SL or FL in cm) and otolith length (OL in mm) are provided for each species. The coefficient of determination is r^2 .

CLUPEIDAE



Alosa sapidissima
(American shad)

Left otolith; length (mm): 3.6

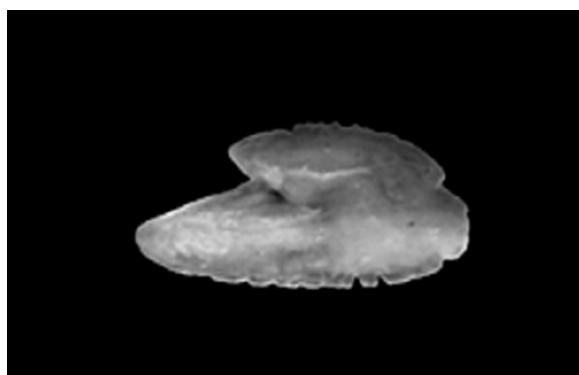
Fish length (cm): 27.3

Fish weight (g): 320.5

Regression equations:

Length: $SL = 11.46 (OL) - 11.08$ $r^2 = 0.960$

Weight: $WT = 0.0135 SL^{3.046}$ $r^2 = 0.997$



Clupea pallasi
(Pacific herring)

Right otolith; length (mm): 3.3

Fish length (cm): 17.7

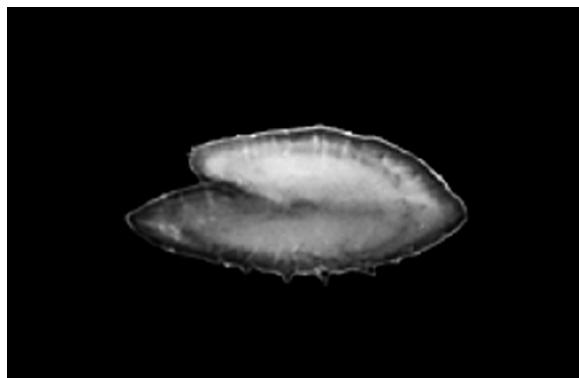
Fish weight (g): 71.6

Regression equations:

Length: $SL = 5.24 (OL) - 1.85$ $r^2 = 0.934$

Weight: $WT = 0.0044 SL^{3.398}$ $r^2 = 0.976$

ENGRAULIDAE



Engraulis mordax
(northern anchovy)

Right otolith; length (mm): 3.5

Fish length (cm): 8.0

Fish weight (g): 7.8

Regression equations:

Length: $SL = 2.28 (OL) + 0.85$ $r^2 = 0.694$

Weight: $WT = 0.0485 SL^{2.413}$ $r^2 = 0.807$



Engraulis mordax
(northern anchovy)

Left otolith; length (mm): 3.4

Fish length (cm): 11.9

Fish weight (g): 12.8

Regression equations:

Length: $SL = 2.28 (OL) + 0.85$ $r^2 = 0.694$

Weight: $WT = 0.0485 SL^{2.413}$ $r^2 = 0.807$

OSMERIDAE



Allosmerus elongatus
(whitebait smelt)

Right otolith; length (mm): 3.0

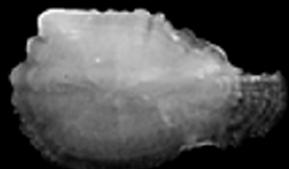
Fish length (cm): 9.3

Fish weight (g): 5.9

Regression equations:

Length: $SL = 2.11 (OL) + 3.02$ $r^2 = 0.838$

Weight: $WT = 0.0063 SL^{3.233}$ $r^2 = 0.893$



Hypomesus pretiosus
(surf smelt)

Left otolith; length (mm): 3.8

Fish length (cm): 12.6

Fish weight (g): 20.1

Regression equations:

Length: $SL = 3.61 (OL) - 0.63$ $r^2 = 0.932$

Weight: $WT = 0.0044 SL^{3.345}$ $r^2 = 0.986$



Mallotus villosus
(capelin)

Right otolith; length (mm): 2.5

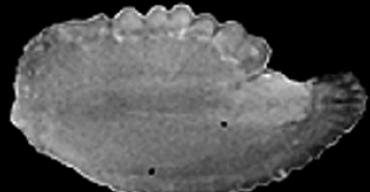
Fish length (cm): 11.6

Fish weight (g): 12.0

Regression equations:

Length: $SL = 3.45 (OL) + 3.62$ $r^2 = 0.649$

Weight: $WT = 0.0054 SL^{3.160}$ $r^2 = 0.717$



Osmerus mordax
(rainbow smelt)

Left otolith; length (mm): 5.1

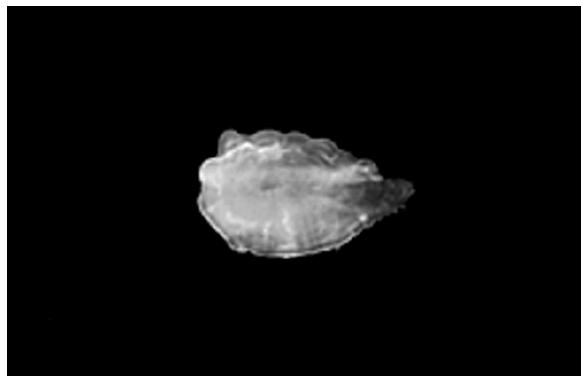
Fish length (cm): 13.0

Fish weight (g): 17.9

Regression equations:

Length: $SL = 2.69 (OL) + 0.32$ $r^2 = 0.759$

Weight: $WT = 0.0038 SL^{3.278}$ $r^2 = 0.819$

OSMERIDAE (cont.)

Spirinchus thaleichthys
(longfin smelt)

Left otolith; length (mm): 3.8

Fish length (cm): 9.9

Fish weight (g): 8.8

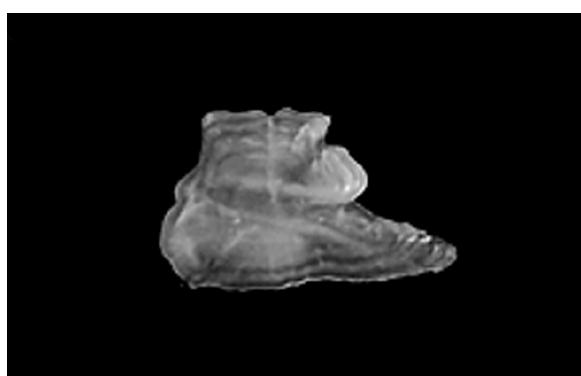
Regression equations:

Length: $SL = 2.64 (OL) - 0.20$

$r^2 = 0.878$

Weight: $WT = 0.0288 SL^{2.531}$

$r^2 = 0.854$



Thaleichthys pacificus
(eulachon)

Left otolith; length (mm): 4.1

Fish length (cm): 16.5

Fish weight (g): 32.7

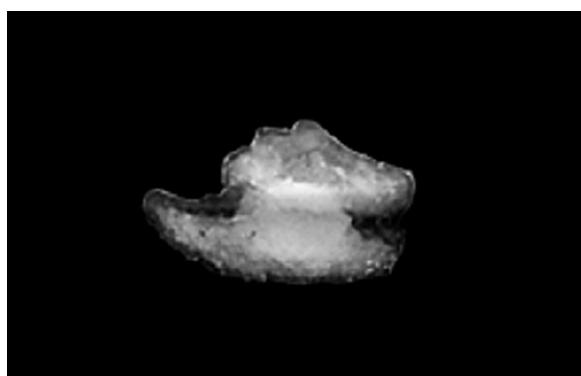
Regression equations:

Length: $SL = 4.71 (OL) - 2.70$

$r^2 = 0.871$

Weight: $WT = 0.0077 SL^{3.075}$

$r^2 = 0.884$

SALMONIDAE

Oncorhynchus kisutch
(coho salmon)

Right otolith; length (mm): 3.7

Fish length (cm): 18.0

Fish weight (g): 98.9

Regression equations:

Length: $SL = 16.31 (OL) - 40.74$

$r^2 = 0.569$

Weight: $WT = 0.0103 SL^{3.092}$

$r^2 = 0.989$



Oncorhynchus kisutch
(coho salmon)

Right otolith; length (mm): 3.3

Fish length (cm): 17.7

Fish weight (g): 66.6

Regression equations:

Length: $SL = 16.31 (OL) - 40.74$

$r^2 = 0.569$

Weight: $WT = 0.0103 SL^{3.092}$

$r^2 = 0.989$

SALMONIDAE (cont.)



Oncorhynchus mykiss
(rainbow trout)

Left otolith; length (mm): 5.0

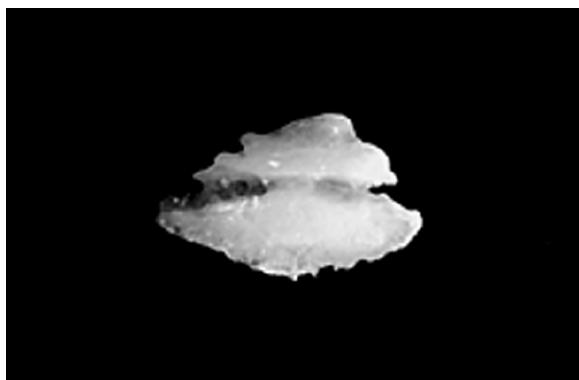
Fish length (cm): 24.3

Fish weight (g): 320.9

Regression equations:

Length: $SL = 16.28 (OL) - 38.14$ $r^2 = 0.790$

Weight: $WT = 0.0275 SL^{2.895}$ $r^2 = 0.905$



Oncorhynchus mykiss
(rainbow trout)

Right otolith; length (mm): 4.8

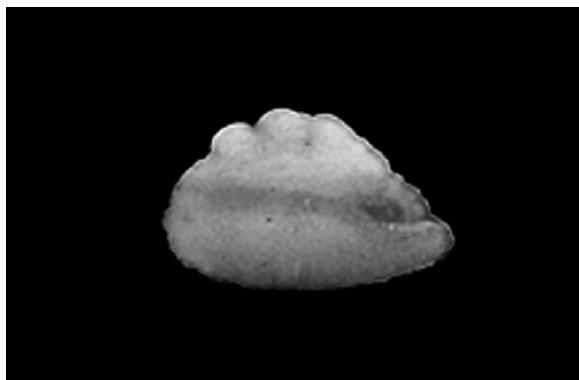
Fish length (cm): 25.3

Fish weight (g): 315.6

Regression equations:

Length: $SL = 16.28 (OL) - 38.14$ $r^2 = 0.790$

Weight: $WT = 0.0275 SL^{2.895}$ $r^2 = 0.905$



Oncorhynchus nerka
(sockeye salmon)

Left otolith; length (mm): 3.0

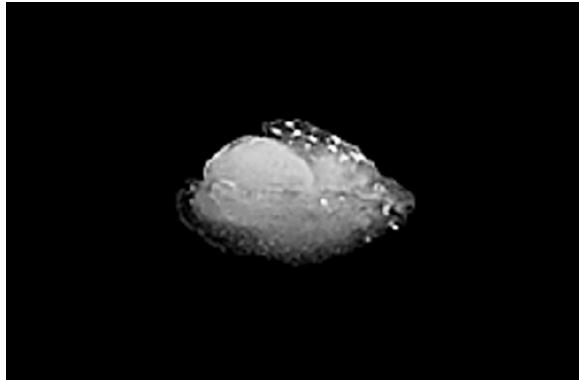
Fish length (cm): 20

Fish weight (g): N/A

Regression equations:

Length: No data available

Weight: No data available



Oncorhynchus tshawytscha
(chinook salmon)

Left otolith; length (mm): 2.4

Fish length (cm): 7.6

Fish weight (g): N/A

Regression equations:

Length: No data available

Weight: No data available

GADIDAE

Eleginus gracilis
(Saffron cod; ventral view)

Left otolith; length (mm): 6.8

Fish length (cm): 9.2

Fish weight (g): 6.2

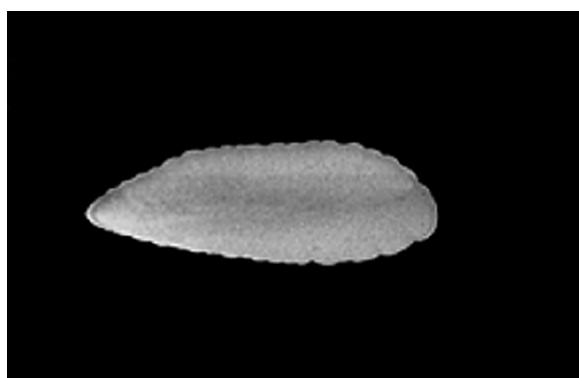
Regression equations:

Length: $SL = 1.89 (OL) - 2.76$

$r^2 = 0.960$

Weight: $WT = 0.0039 SL^{3.292}$

$r^2 = 0.990$



Eleginus gracilis
(saffron cod)

Left otolith; length (mm): 6.8

Fish length (cm): 9.2

Fish weight (g): 6.2

Regression equations:

Length: $SL = 1.89 (OL) - 2.76$

$r^2 = 0.960$

Weight: $WT = 0.0039 SL^{3.292}$

$r^2 = 0.990$



Gadus macrocephalus
(Pacific cod)

Right otolith; length (mm): 12.0

Fish length (cm): 29.5

Fish weight (g): 373.8

Regression equations:

Length: $FL = 4.51 (OL) - 22.97$

$r^2 = 0.883$

Weight: No data available



Merluccius productus
(Pacific hake)

Right otolith; length (mm): 22.0

Fish length (cm): 42.0

Fish weight (g): 659.0

Regression equations:

Length: $SL = 2.04 (OL) + 0.96$

$r^2 = 0.891$

Weight: $WT = 0.0081 SL^{2.966}$

$r^2 = 0.933$

GADIDAE (cont.)



Microgadus proximus
(Pacific tomcod)

Right otolith; length (mm): 12.3

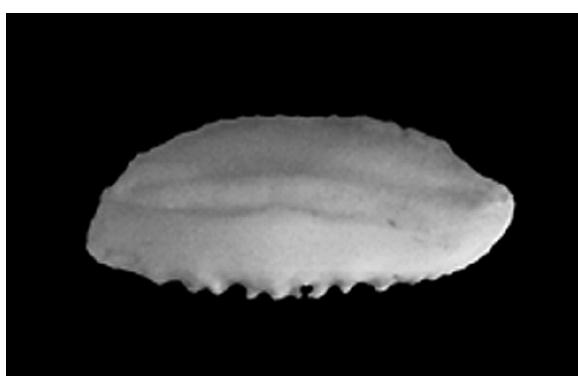
Fish length (cm): 18.2

Fish weight (g): 59.8

Regression equations:

Length: $SL = 1.77 (OL) - 3.51$ $r^2 = 0.932$

Weight: $WT = 0.0064 SL^{3.191}$ $r^2 = 0.988$



Theragra chalcogramma
(walleye pollock)

Left otolith; length (mm): 16.0

Fish length (cm): 33.5

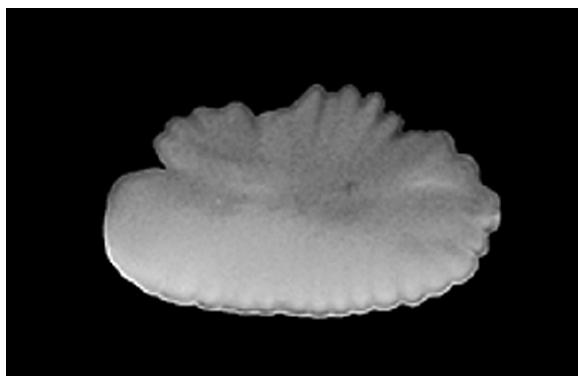
Fish weight (g): 394.0

Regression equations:

Length: $SL = 2.24 (OL) - 2.35$ $r^2 = 0.948$

Weight: $WT = 0.0043 SL^{3.255}$ $r^2 = 0.985$

MACROURIDAE



Coryphaenoides acrolepis
(Pacific rattail)

Right otolith; length (mm): 10.0

Fish length (cm): 36.0

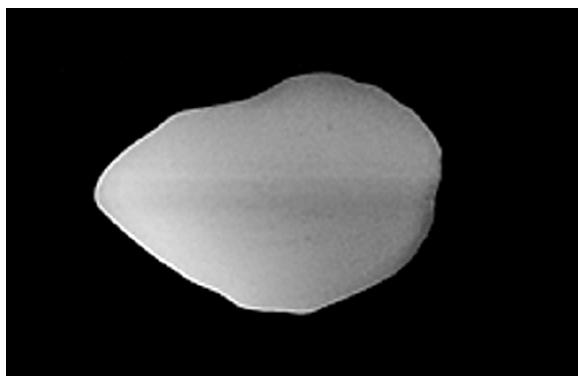
Fish weight (g): 148.8

Regression equations:

Length: $SL = 3.44 (OL) - 3.23$ $r^2 = 0.926$

Weight: $WT = 0.0016 SL^{3.209}$ $r^2 = 0.921$

OPHIDIIDAE



Chilara taylori
(spotted cusk-eel)

Left otolith; length (mm): 7.6

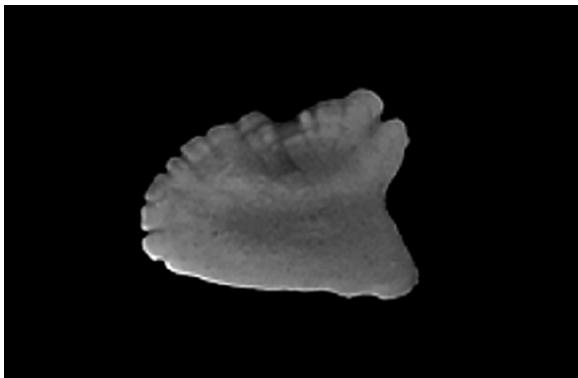
Fish length (cm): 21.8

Fish weight (g): 46.6

Regression equations:

Length: $SL = 2.51 (OL) + 2.15$ $r^2 = 0.730$

Weight: $WT = 0.0004 SL^{3.761}$ $r^2 = 0.964$

BATRACHOIDIDAE

Porichthys notatus
(plainfin midshipman)

Left otolith; length (mm): 9.1

Fish length (cm): 22.5

Fish weight (g): 215.1

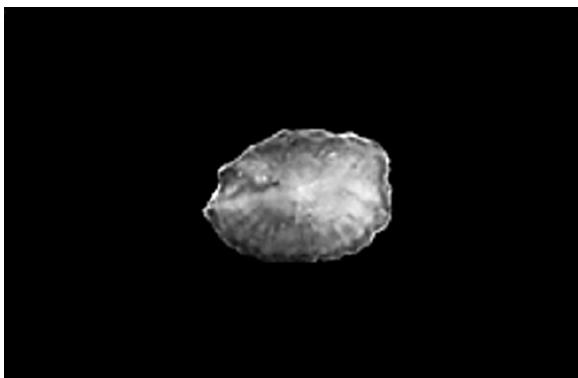
Regression equations:

Length: $SL = 2.80 (OL) - 2.59$

$r^2 = 0.926$

Weight: $WT = 0.0207 SL^{2.916}$

$r^2 = 0.967$

ATHERINIDAE

Atherinops affinis
(topsmelt)

Right otolith; length (mm): 2.4

Fish length (cm): 9.9

Fish weight (g): 10.2

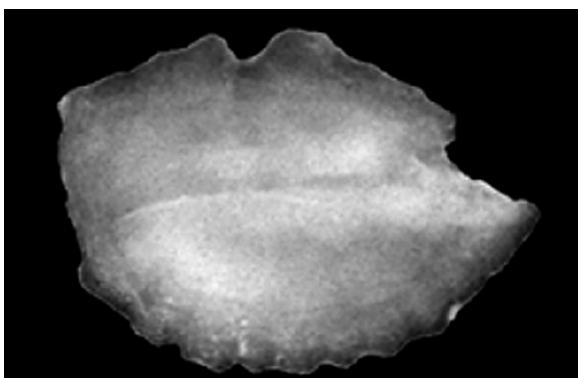
Regression equations:

Length: $SL = 3.72 (OL) + 0.55$

$r^2 = 0.891$

Weight: $WT = 0.1698 SL^{1.733}$

$r^2 = 0.429$



Atherinops affinis
(topsmelt)

Left otolith; length (mm): 3.2

Fish length (cm): 11.8

Fish weight (g): 13.2

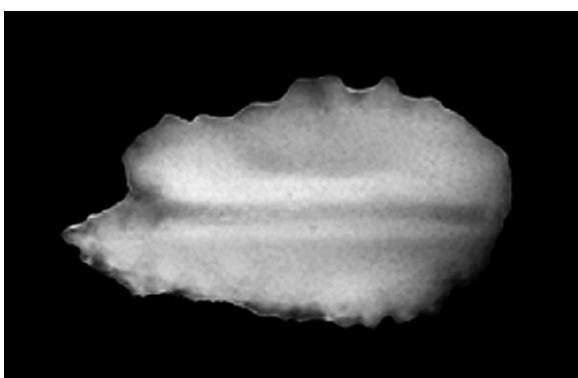
Regression equations:

Length: $SL = 3.72 (OL) + 0.55$

$r^2 = 0.891$

Weight: $WT = 0.1698 SL^{1.733}$

$r^2 = 0.429$



Atherinopsis californiensis
(jacksmelt)

Right otolith; length (mm): 6.1

Fish length (cm): 28.7

Fish weight (g): 260.0

Regression equations:

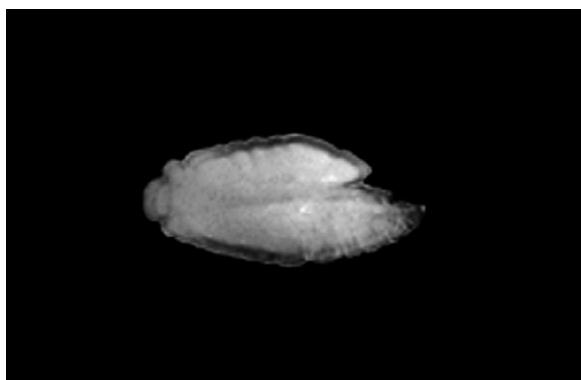
Length: $SL = 4.85 (OL) - 2.46$

$r^2 = 0.950$

Weight: $WT = 0.0049 SL^{3.228}$

$r^2 = 0.968$

SCORPAENIDAE



Sebastes auriculatus
(brown rockfish)

Left otolith; length (mm): 3.2

Fish length (cm): 6.7

Fish weight (g): 6.9

Regression equations:

Length: $SL = 3.32 (OL) - 5.30$ $r^2 = 0.940$

Weight: No data available



Sebastes constellatus
(starry rockfish)

Right otolith; length (mm): 12.3

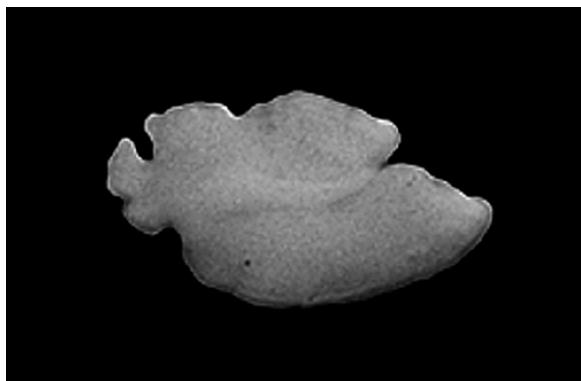
Fish length (cm): N/A

Fish weight (g): N/A

Regression equations:

Length: $SL = 2.53 (OL) - 3.75$ $r^2 = 0.960$

Weight: No data available



Sebastes crameri
(darkblotched rockfish)

Left otolith; length (mm): 13.9

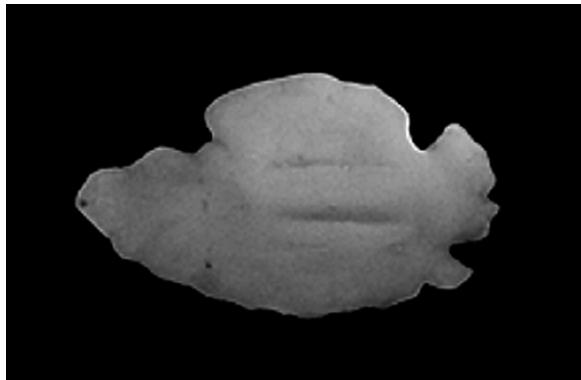
Fish length (cm): 31.0

Fish weight (g): 1121.5

Regression equations:

Length: $SL = 2.81 (OL) - 2.71$ $r^2 = 0.940$

Weight: No data available



Sebastes diploproa
(splitnose rockfish)

Right otolith; length (mm): 15.1

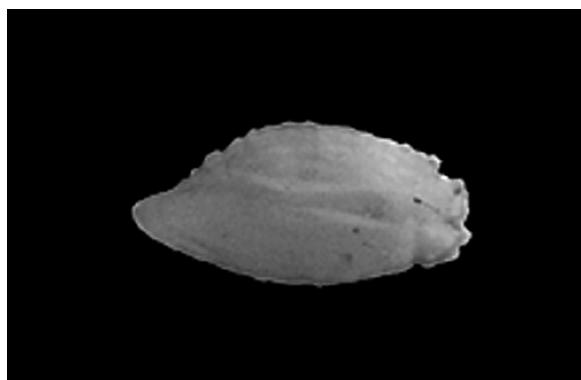
Fish length (cm): N/A

Fish weight (g): N/A

Regression equations:

Length: $SL = 2.26 (OL) - 1.29$ $r^2 = 0.960$

Weight: No data available

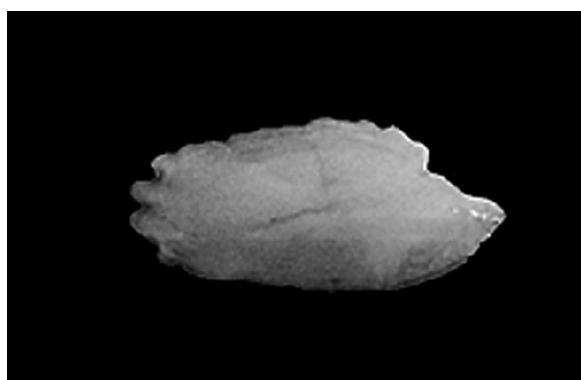
SCORPAENIDAE (cont.)***Sebastes flavidus*
(yellowtail rockfish)**

Right otolith; length (mm): 12.2

Fish length (cm): 24.5

Fish weight (g): N/A

Regression equations:

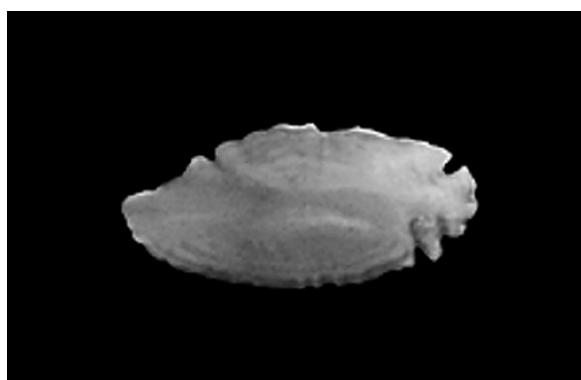
Length: $SL = 2.65 (OL) - 1.09$ $r^2 = 0.880$ **Weight:** No data available***Sebastes maliger*
(quillback rockfish)**

Left otolith; length (mm): 13.0

Fish length (cm): 32.5

Fish weight (g): N/A

Regression equations:

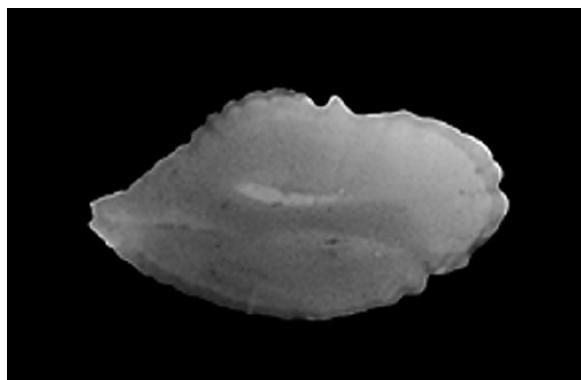
Length: $SL = 2.99 (OL) - 5.31$ $r^2 = 0.860$ **Weight:** No data available***Sebastes melanops*
(black rockfish)**

Right otolith; length (mm): 12.4

Fish length (cm): 29.0

Fish weight (g): N/A

Regression equations:

Length: $SL = 2.23 (OL) - 1.48$ $r^2 = 0.749$ **Weight:** $WT = 0.1225 SL^{2.499}$ $r^2 = 0.585$ ***Sebastes miniatus*
(vermillion rockfish)**

Right otolith; length (mm): 15.1

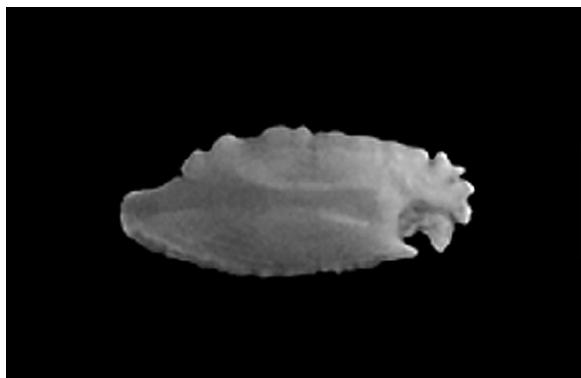
Fish length (cm): 35.5

Fish weight (g): N/A

Regression equations:

Length: $SL = 2.94 (OL) - 5.67$ $r^2 = 0.930$ **Weight:** No data available

SCORPAENIDAE (cont.)



Sebastes mystinus
(blue rockfish)

Right otolith; length (mm): 12.8

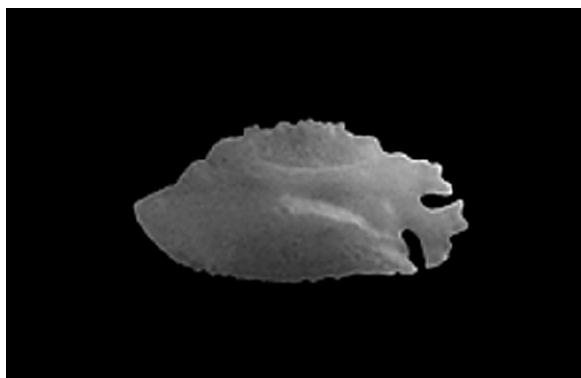
Fish length (cm): 29.0

Fish weight (g): N/A

Regression equations:

Length: $SL = 2.98 (OL) - 1.82$ $r^2 = 0.830$

Weight: No data available



Sebastes nebulosus
(China rockfish)

Right otolith; length (mm): 10.7

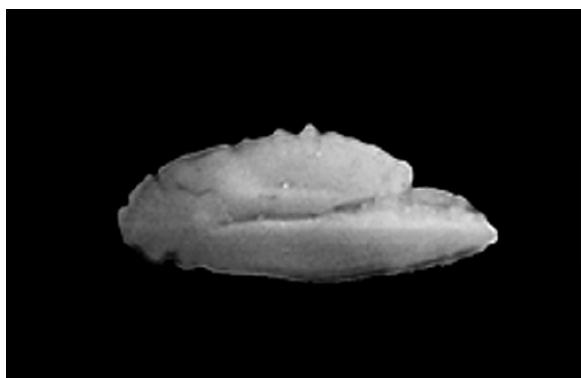
Fish length (cm): N/A

Fish weight (g): N/A

Regression equations:

Length: $SL = 2.52 (OL) + 3.30$ $r^2 = 0.790$

Weight: No data available



Sebastes paucispinis
(boccacio)

Left otolith; length (mm): 14.0

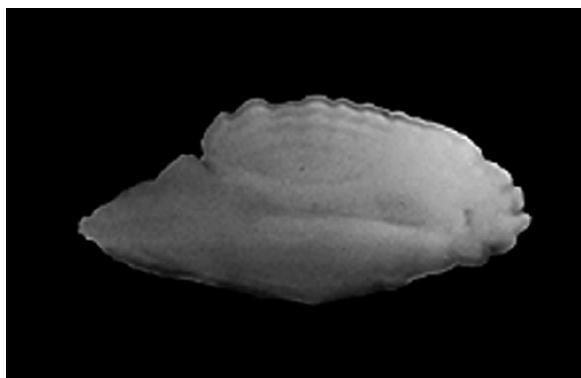
Fish length (cm): 39.8

Fish weight (g): 1191.8

Regression equations:

Length: $SL = 2.41 (OL) + 0.14$ $r^2 = 0.769$

Weight: No data available



Sebastes pinniger
(canary rockfish)

Right otolith; length (mm): 16.3

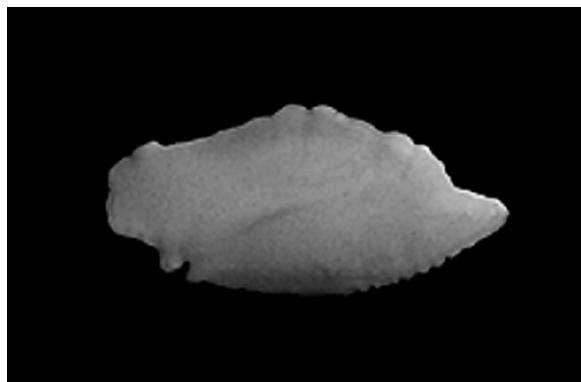
Fish length (cm): 31.8

Fish weight (g): N/A

Regression equations:

Length: $SL = 2.94 (OL) - 8.51$ $r^2 = 0.920$

Weight: No data available

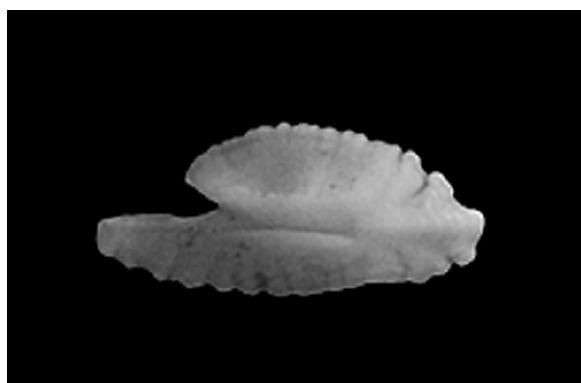
SCORPAENIDAE (cont.)***Sebastes ruberrimus*
(yellow eye rockfish)**

Left otolith; length (mm): 14.4

Fish length (cm): 34.0

Fish weight (g): N/A

Regression equations:

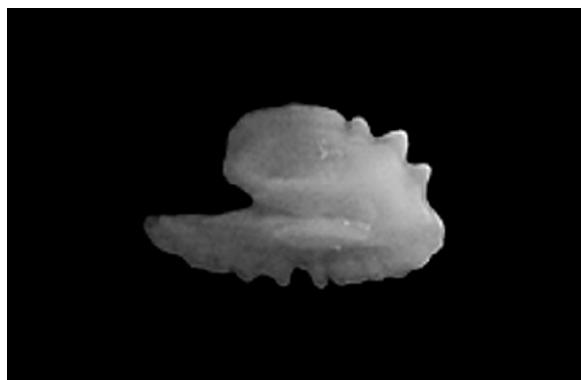
Length: $SL = 3.13 (OL) - 7.62$ $r^2 = 0.920$ **Weight:** No data available***Sebastolobus alascanus*
(shortspine thornyhead)**

Right otolith; length (mm): 14.1

Fish length (cm): 27.7

Fish weight (g): 515.6

Regression equations:

Length: $SL = 2.31 (OL) - 3.71$ $r^2 = 0.828$ **Weight:** $WT = 0.0102 SL^{3.239}$ $r^2 = 0.988$ ***Sebastolobus altivelis*
(longspine thornyhead)**

Right otolith; length (mm): 10.9

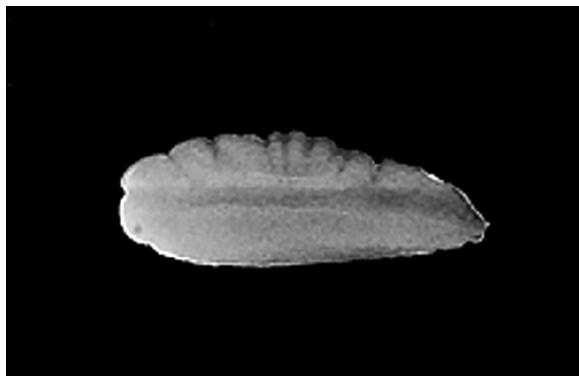
Fish length (cm): 24.5

Fish weight (g): 328.8

Regression equations:

Length: $SL = 4.94 (OL) - 27.50$ $r^2 = 0.839$ **Weight:** $WT = 0.0155 SL^{3.113}$ $r^2 = 0.997$

ANOPLOPOMATIDAE



Anoplopoma fimbria
(sablefish)

Left otolith; length (mm): 6.2

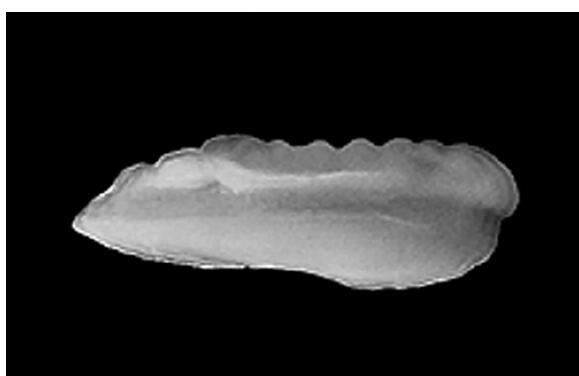
Fish length (cm): 36.4

Fish weight (g): 541.7

Regression equations:

Length: $SL = 5.28 (OL) + 1.62$ $r^2 = 0.955$

Weight: $WT = 0.0163 SL^{2.902}$ $r^2 = 0.993$



Anoplopoma fimbria
(sablefish)

Right otolith; length (mm): 7.7

Fish length (cm): 41.6

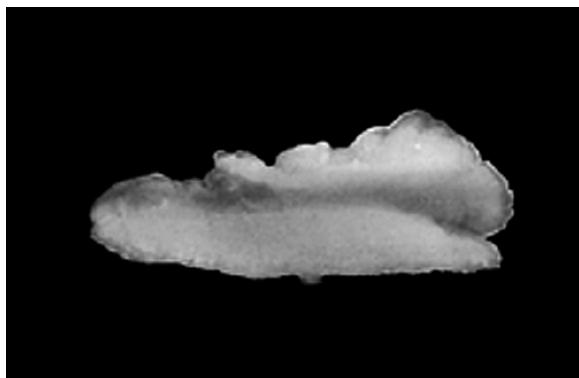
Fish weight (g): 868.1

Regression equations:

Length: $SL = 5.28 (OL) + 1.62$ $r^2 = 0.955$

Weight: $WT = 0.0163 SL^{2.902}$ $r^2 = 0.993$

HEXAGRAMMIDAE



Ophiodon elongatus
(lingcod)

Right otolith; length (mm): 9.1

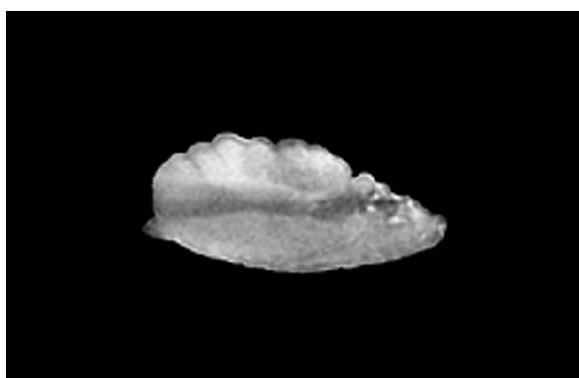
Fish length (cm): 62.0

Fish weight (g): N/A

Regression equations:

Length: $SL = 8.23 (OL) - 8.20$ $r^2 = 0.722$

Weight: $WT = 0.0023 SL^{3.567}$ $r^2 = 0.620$



Ophiodon elongatus
(lingcod)

Left otolith; length (mm): 5.3

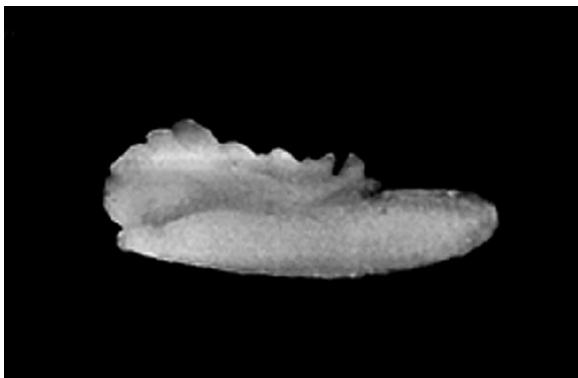
Fish length (cm): 38.2

Fish weight (g): N/A

Regression equations:

Length: $SL = 8.23 (OL) - 8.20$ $r^2 = 0.722$

Weight: $WT = 0.0023 SL^{3.567}$ $r^2 = 0.620$

HEXAGRAMMIDAE (cont.)

Ophiodon elongatus
(lingcod)

Left otolith; length (mm): 9.0

Fish length (cm): 62.0

Fish weight (g): N/A

Regression equations:

Length: $SL = 8.23 (OL) - 8.20$

$r^2 = 0.722$

Weight: $WT = 0.0023 SL^{3.567}$

$r^2 = 0.620$



Pleurogrammus monopterygius
(Atka mackerel)

Right otolith; length (mm): 3.5

Fish length (cm): 21.2

Fish weight (g): 108.8

Regression equations:

Length: $FL = 8.40 (OL) - 4.99$

$r^2 = 0.864$

Weight: $WT = 0.0034 FL^{3.401}$

$r^2 = 0.987$

COTTIDAE

Chitonotus pugetensis
(roughback sculpin)

Right otolith; length (mm): 2.9

Fish length (cm): 6.0

Fish weight (g): 3.3

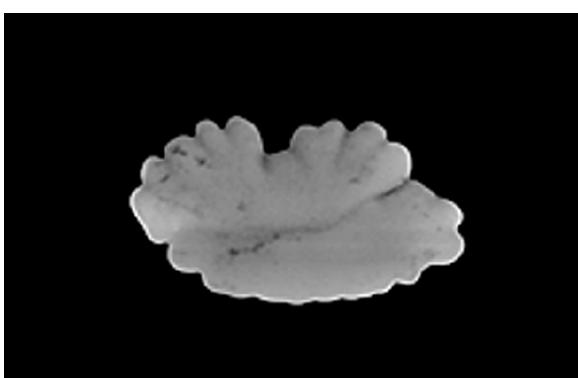
Regression equations:

Length: $SL = 3.37 (OL) - 4.52$

$r^2 = 0.857$

Weight: $WT = 0.0217 SL^{2.871}$

$r^2 = 0.960$



Dasycottus setiger
(spinyhead sculpin)

Left otolith; length (mm): 8.5

Fish length (cm): N/A

Fish weight (g): N/A

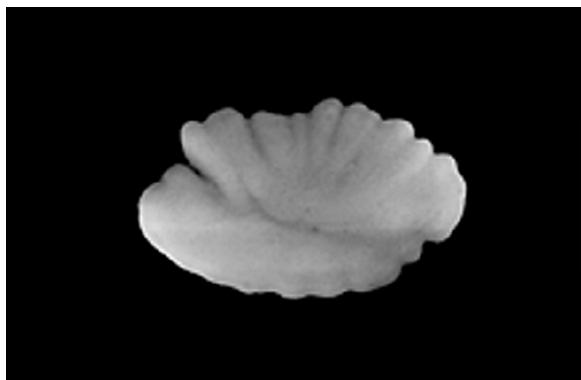
Regression equations:

Length: $FL = 3.11 (OL) - 7.03$

$r^2 = 0.655$

Weight: No data available

COTTIDAE (cont.)



Dasy cottus setiger
(spinyhead sculpin)

Right otolith; length (mm): 8.3

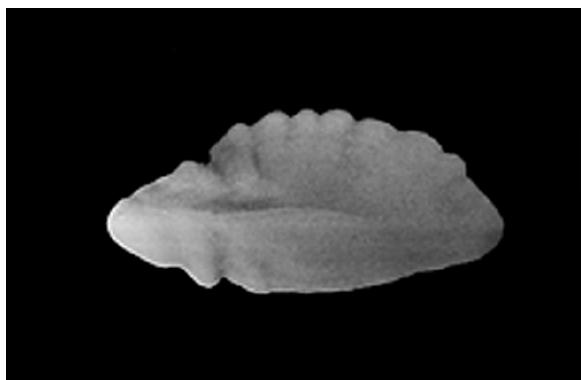
Fish length (cm): N/A

Fish weight (g): N/A

Regression equations:

Length: $FL = 3.11 (OL) - 7.03$ $r^2 = 0.655$

Weight: No data available



Gymnophanthis galeatus
(armorhead sculpin)

Right otolith; length (mm): 6.6

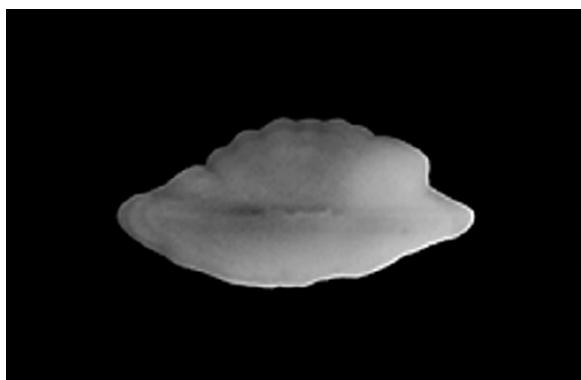
Fish length (cm): 13.4

Fish weight (g): 43.5

Regression equations:

Length: $SL = 1.75 (OL) + 0.82$ $r^2 = 0.476$

Weight: $WT = 0.0100 SL^{3.196}$ $r^2 = 0.939$



Gymnophanthis galeatus
(armorhead sculpin)

Right otolith; length (mm): 6.5

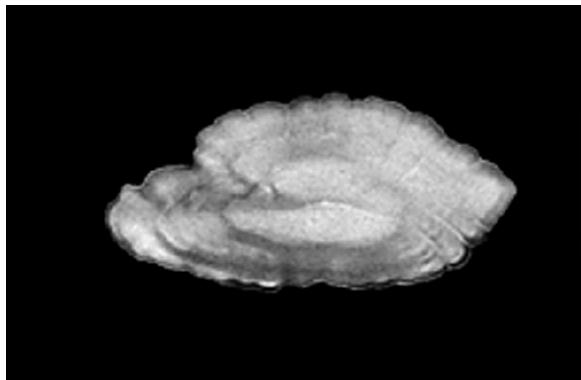
Fish length (cm): 11.3

Fish weight (g): 22.4

Regression equations:

Length: $SL = 1.75 (OL) + 0.82$ $r^2 = 0.476$

Weight: $WT = 0.0100 SL^{3.196}$ $r^2 = 0.939$



Leptocottus armatus
(Pacific staghorn sculpin)

Right otolith; length (mm): 5.2

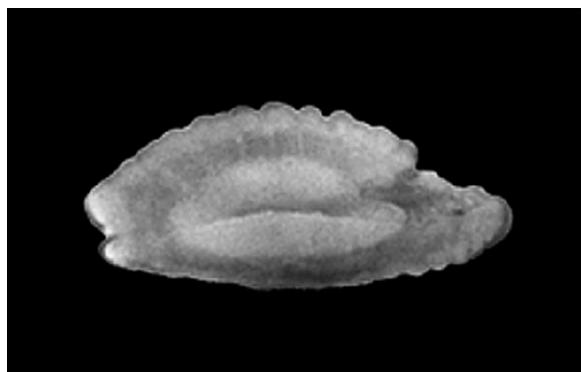
Fish length (cm): 11.5

Fish weight (g): 30.5

Regression equations:

Length: $SL = 2.58 (OL) - 2.26$ $r^2 = 0.928$

Weight: $WT = 0.0111 SL^{3.229}$ $r^2 = 0.990$

COTTIDAE (cont.)

Leptocottus armatus
(Pacific staghorn sculpin)

Left otolith; length (mm): 5.8

Fish length (cm): 13.6

Fish weight (g): 46.5

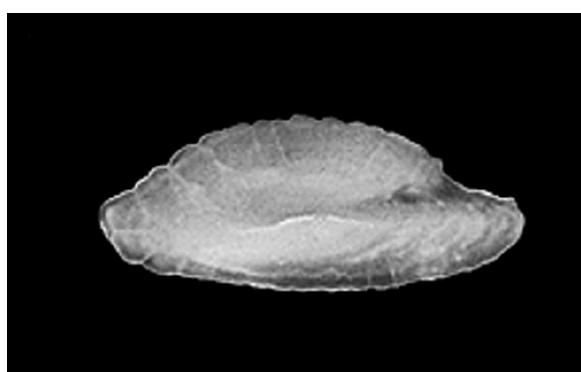
Regression equations:

Length: $SL = 2.58 (OL) - 2.26$

$r^2 = 0.928$

Weight: $WT = 0.0111 SL^{3.229}$

$r^2 = 0.990$



Leptocottus armatus
(Pacific staghorn sculpin)

Left otolith; length (mm): 6.1

Fish length (cm): 13.5

Fish weight (g): 47.8

Regression equations:

Length: $SL = 2.58 (OL) - 2.26$

$r^2 = 0.928$

Weight: $WT = 0.0111 SL^{3.229}$

$r^2 = 0.990$

AGONIDAE

Podothecus acipenserinus
(sturgeon poacher)

Right otolith; length (mm): 4.2

Fish length (cm): 19.1

Fish weight (g): 54.0

Regression equations:

Length: $SL = 6.58 (OL) - 6.21$

$r^2 = 0.840$

Weight: $WT = 0.0030 SL^{3.233}$

$r^2 = 0.956$

CARANGIDAE

Trachurus symmetricus
(Jack mackerel)

Right otolith; length (mm): 7.6

Fish length (cm): 26.8

Fish weight (g): 266.0

Regression equations:

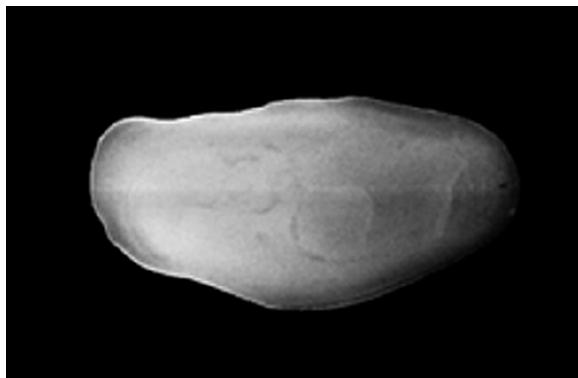
Length: Not significant

$r^2 = 0.141$

Weight: $WT = 0.0635 SL^{2.556}$

$r^2 = 0.761$

SCIENIDAE



Genyonemus lineatus
(white croaker)

Left otolith; length (mm): 10.2

Fish length (cm): 20.5

Fish weight (g): 171.8

Regression equations:

Length: $SL = 1.52 (OL) + 4.66$ $r^2 = 0.534$

Weight: $WT = 0.0550 SL^{2.700}$ $r^2 = 0.767$



Genyonemus lineatus (lateral view)
(white croaker)

Left otolith; length (mm): 10.2

Fish length (cm): 20.5

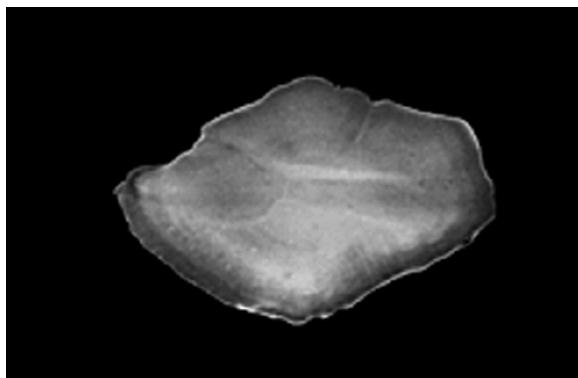
Fish weight (g): 171.8

Regression equations:

Length: $SL = 1.52 (OL) + 4.66$ $r^2 = 0.534$

Weight: $WT = 0.0550 SL^{2.700}$ $r^2 = 0.767$

EMBIOTOCIDAE



Cymatogaster aggregata
(shiner perch)

Right otolith; length (mm): 6.3

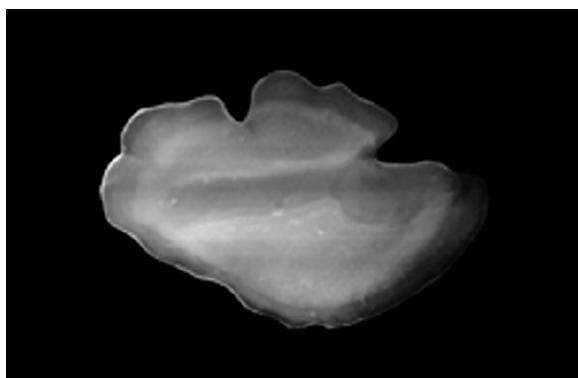
Fish length (cm): 10.1

Fish weight (g): 35.7

Regression equations:

Length: $SL = 1.74 (OL) - 0.52$ $r^2 = 0.925$

Weight: $WT = 0.0100 SL^{3.515}$ $r^2 = 0.979$



Cymatogaster aggregata
(shiner perch)

Left otolith; length (mm): 6.3

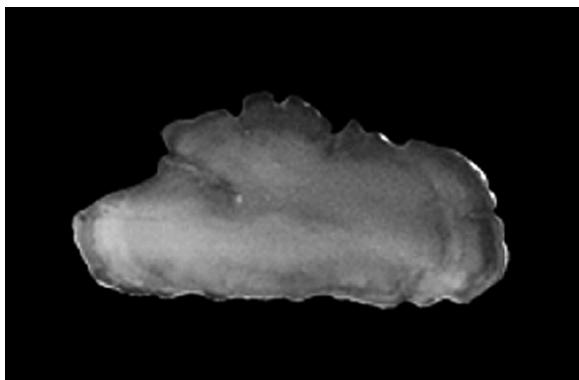
Fish length (cm): 10.7

Fish weight (g): 38.6

Regression equations:

Length: $SL = 1.74 (OL) - 0.52$ $r^2 = 0.925$

Weight: $WT = 0.0100 SL^{3.515}$ $r^2 = 0.979$

EMBIOTOCIDAE (cont.)

Embiotoca jacksoni
(black perch)

Right otolith; length (mm): 7.4

Fish length (cm): 15.6

Fish weight (g): 169.0

Regression equations:

Length: $SL = 2.45 (OL) - 2.61$

$r^2 = 0.947$

Weight: $WT = 0.0282 SL^{3.148}$

$r^2 = 0.992$



Embiotoca lateralis
(striped seaperch)

Right otolith; length (mm): 10.5

Fish length (cm): 24.2

Fish weight (g): 540.2

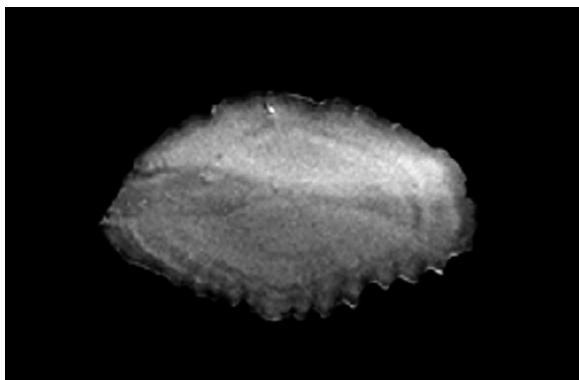
Regression equations:

Length: $SL = 2.90 (OL) - 5.68$

$r^2 = 0.990$

Weight: $WT = 0.0329 SL^{3.043}$

$r^2 = 0.998$



Hyperprosopon argenteum
(walleye surfperch)

Right otolith; length (mm): 7.9

Fish length (cm): 18.7

Fish weight (g): 213.0

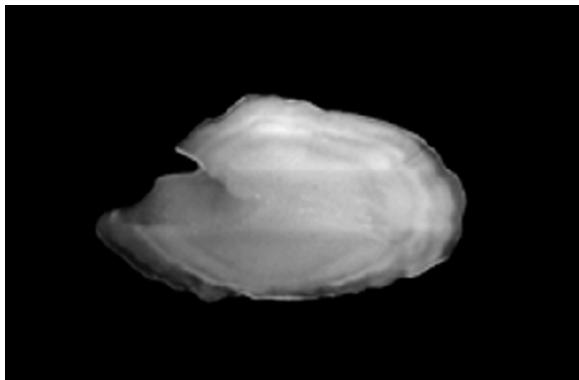
Regression equations:

Length: $SL = 2.57 (OL) - 2.83$

$r^2 = 0.987$

Weight: $WT = 0.0116 SL^{3.361}$

$r^2 = 0.996$



Phanerodon furcatus
(white seaperch)

Right otolith; length (mm): 8.7

Fish length (cm): 23.5

Fish weight (g): 402.2

Regression equations:

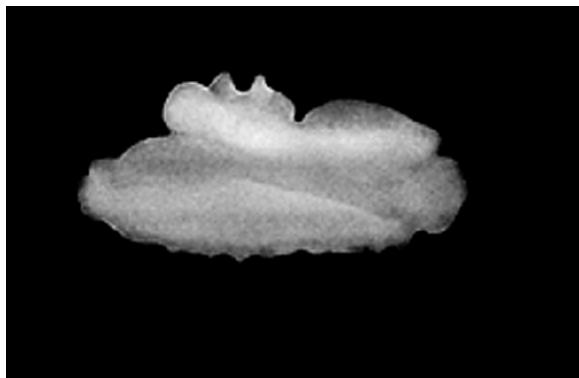
Length: $SL = 2.33 (OL) - 2.15$

$r^2 = 0.912$

Weight: $WT = 0.0213 SL^{3.086}$

$r^2 = 0.997$

EMBIOTOCIDAE (cont.)



Rhacochilus vacca
(pile perch)

Right otolith; length (mm): 11.8

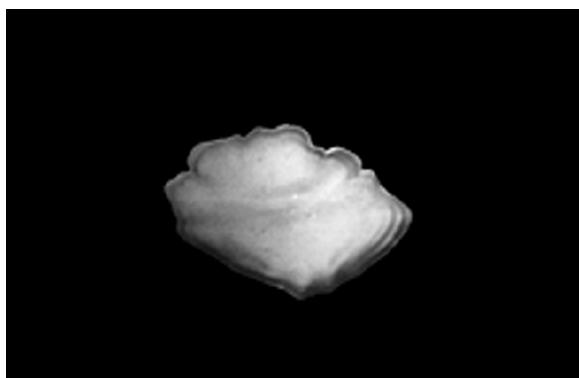
Fish length (cm): 31.2

Fish weight (g): 1326.40

Regression equations:

Length: $SL = 3.35 (OL) - 8.19$ $r^2 = 0.965$

Weight: $WT = 0.0182 SL^{3.218}$ $r^2 = 0.997$



Zalembius rosaceus
(pink seaperch)

Left otolith; length (mm): 4.7

Fish length (cm): 8.9

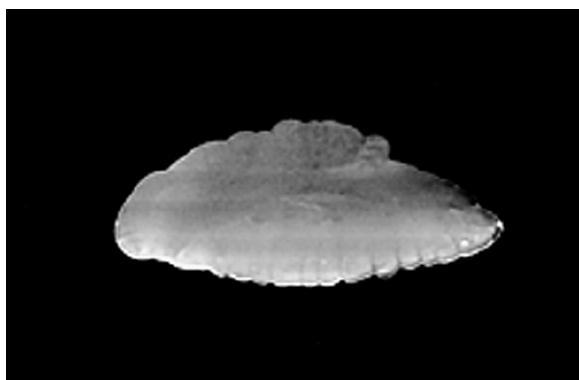
Fish weight (g): 19.0

Regression equations:

Length: $SL = 1.88 (OL) - 0.07$ $r^2 = 0.912$

Weight: $WT = 0.0199 SL^{3.102}$ $r^2 = 0.841$

BATHYMASTERIDAE



Bathymaster signatus
(searcher)

Left otolith; length (mm): 6.3

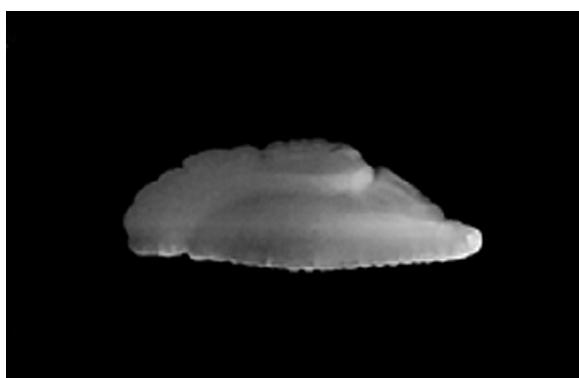
Fish length (cm): 21.0

Fish weight (g): 150.3

Regression equations:

Length: $SL = 3.48 (OL) + 1.90$ $r^2 = 0.883$

Weight: $WT = 0.0038 SL^{3.256}$ $r^2 = 0.991$



Bathymaster signatus
(searcher)

Left otolith; length (mm): 6.9

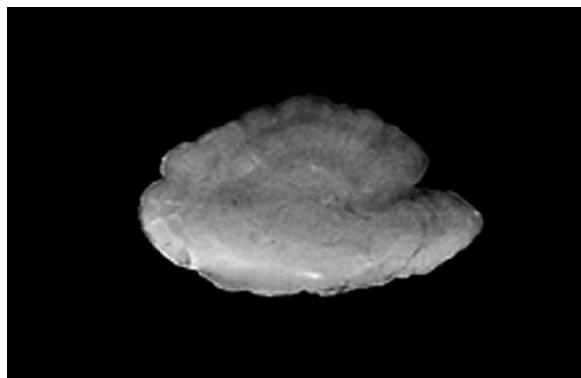
Fish length (cm): 23.3

Fish weight (g): 212.9

Regression equations:

Length: $SL = 3.48 (OL) + 1.90$ $r^2 = 0.883$

Weight: $WT = 0.0038 SL^{3.256}$ $r^2 = 0.991$

ZOARCIDAE

Lycodes brevipes
(shortfin eelpout)

Left otolith; length (mm): 5.1

Fish length (cm): 24.0

Fish weight (g): 61.3

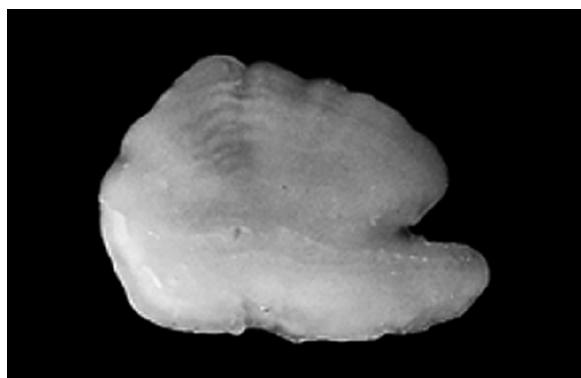
Regression equations:

Length: $FL = 3.47 (OL) + 4.83$

$r^2 = 0.520$

Weight: $WT = 0.0195 FL^{2.522}$

$r^2 = 0.826$



Lycodes corteziatus
(bigfin eelpout)

Left otolith; length (mm): 4.9

Fish length (cm): 38.5

Fish weight (g): 286.8

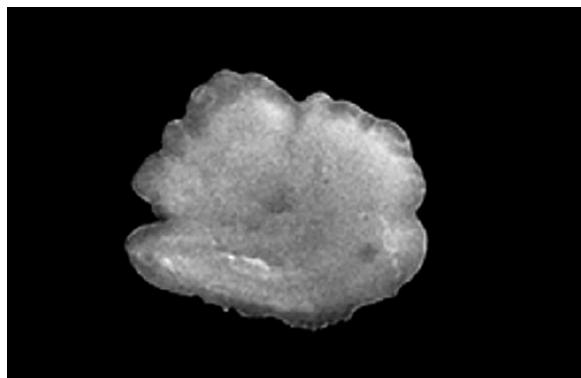
Regression equations:

Length: $SL = 10.96 (OL) - 21.82$

$r^2 = 0.742$

Weight: $WT = 0.0018 SL^{3.245}$

$r^2 = 0.993$



Lycodopsis pacifica
(blackbelly eelpout)

Right otolith; length (mm): 3.6

Fish length (cm): 19.5

Fish weight (g): 30.6

Regression equations:

Length: $SL = 3.82 (OL) + 4.89$

$r^2 = 0.610$

Weight: $WT = 0.0018 SL^{3.302}$

$r^2 = 0.954$

TRICHODONTIDAE



Trichodon trichodon
(Pacific sandfish)

Right otolith; length (mm): 4.0

Fish length (cm): N/A

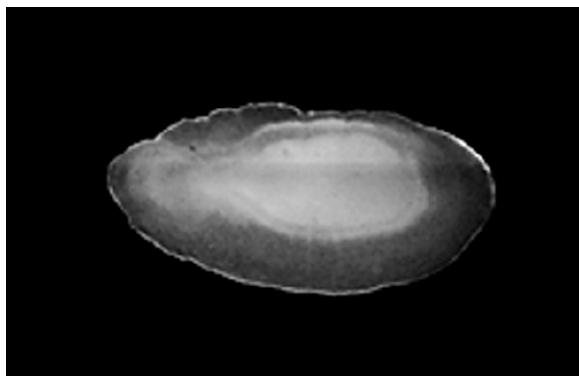
Fish weight (g): N/A

Regression equations:

Length: $FL = 6.06 (OL) - 4.57$ $r^2 = 0.684$

Weight: $WT = 0.0170 FL^{2.953}$ $r^2 = 0.971$

AMMODYTIDAE



Ammodytes hexapterus
(Pacific sand lance)

Right otolith; length (mm): 2.4

Fish length (cm): 11.7

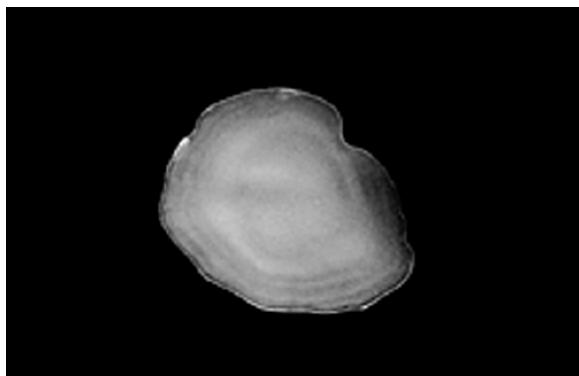
Fish weight (g): 6.4

Regression equations:

Length: $SL = 4.06 (OL) + 2.01$ $r^2 = 0.433$

Weight: $WT = 0.0063 SL^{2.790}$ $r^2 = 0.913$

BOTHIDAE



Citharichthys sordidus
(Pacific sanddab)

Left otolith; length (mm): 6.3

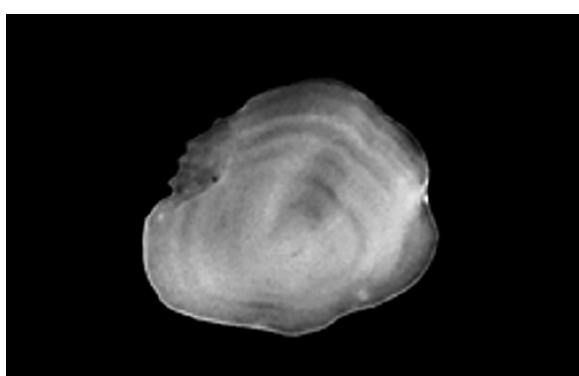
Fish length (cm): 23.0

Fish weight (g): 175.8

Regression equations:

Length: $SL = 2.87 (OL) + 3.29$ $r^2 = 0.727$

Weight: $WT = 0.0352 SL^{2.710}$ $r^2 = 0.851$



Citharichthys sordidus
(Pacific sanddab)

Right otolith; length (mm): 5.8

Fish length (cm): 20.6

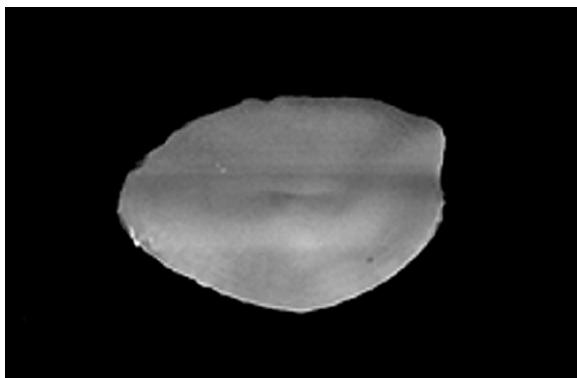
Fish weight (g): 119.5

Regression equations:

Length: $SL = 2.87 (OL) + 3.29$ $r^2 = 0.727$

Weight: $WT = 0.0352 SL^{2.710}$ $r^2 = 0.851$

PLEURONECTIDAE



Atheresthes stomias
(arrowtooth flounder)

Right otolith; length (mm): 9.0

Fish length (cm): 37.5

Fish weight (g): 662.6

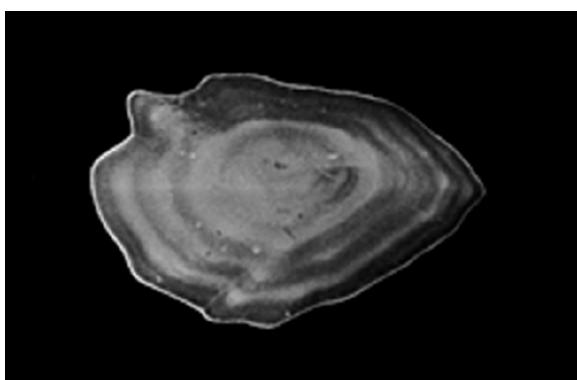
Regression equations:

Length: $FL = 4.75 (OL) - 2.96$

$r^2 = 0.925$

Weight: $WT = 0.0093 FL^{2.999}$

$r^2 = 0.961$



Eopsetta exilis
(slender sole)

Left otolith; length (mm): 4.6

Fish length (cm): 19.6

Fish weight (g): 95.4

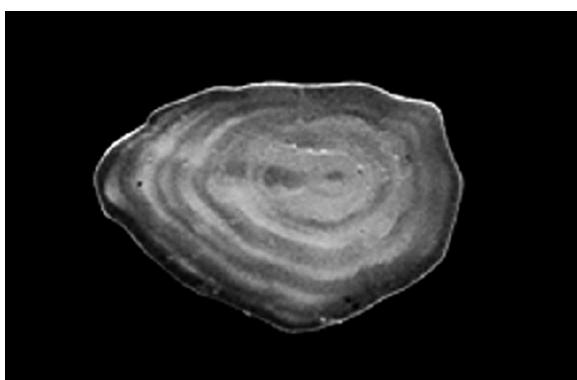
Regression equations:

Length: $SL = 3.37 (OL) + 1.08$

$r^2 = 0.771$

Weight: $WT = 0.0058 SL^{3.293}$

$r^2 = 0.974$



Eopsetta exilis
(slender sole)

Right otolith; length (mm): 4.6

Fish length (cm): 18.5

Fish weight (g): 61.0

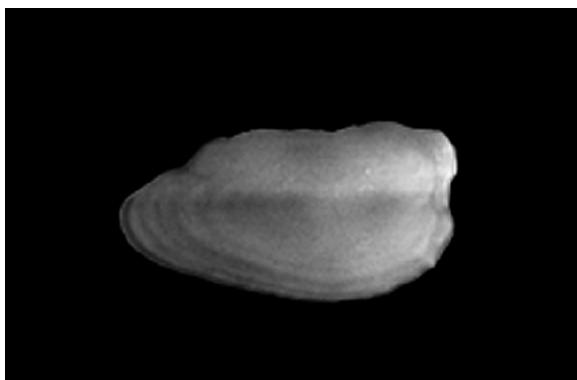
Regression equations:

Length: $SL = 3.37 (OL) + 1.08$

$r^2 = 0.771$

Weight: $WT = 0.0058 SL^{3.293}$

$r^2 = 0.974$



Eopsetta jordani
(petrale sole)

Right otolith; length (mm): 7.3

Fish length (cm): 29.0

Fish weight (g): 502.7

Regression equations:

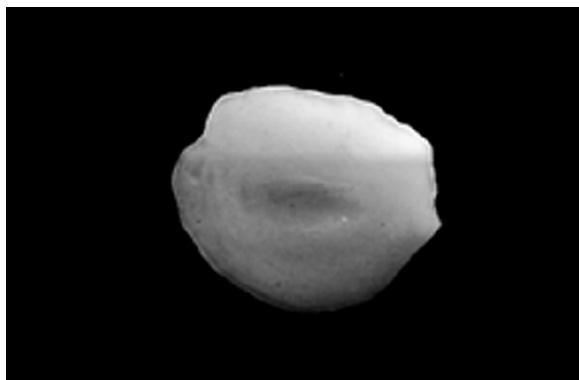
Length: $SL = 4.85 (OL) - 4.81$

$r^2 = 0.857$

Weight: $WT = 0.0086 SL^{3.231}$

$r^2 = 0.986$

PLEURONECTIDAE (cont.)



Errex zachirus
(rex sole)

Right otolith; length (mm): 6.6

Fish length (cm): 27.2

Fish weight (g): 171.0

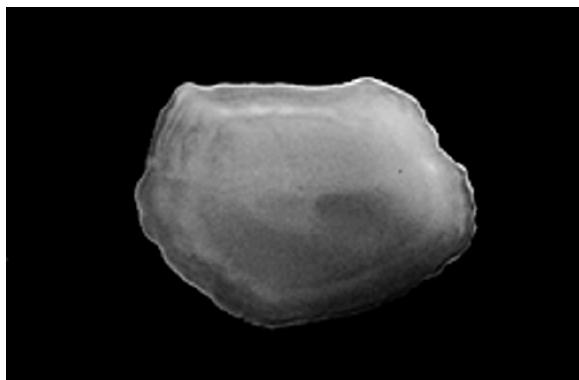
Regression equations:

Length: $SL = 4.80 (OL) - 2.50$

$r^2 = 0.869$

Weight: $WT = 0.0238 SL^{2.692}$

$r^2 = 0.932$



Hippoglossoides elassodon
(flathead sole)

Left otolith; length (mm): 5.5

Fish length (cm): 19.1

Fish weight (g): 117.3

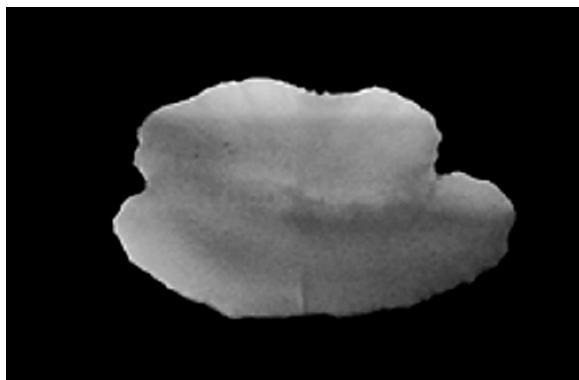
Regression equations:

Length: $FL = 4.63 (OL) - 0.71$

$r^2 = 0.947$

Weight: $WT = 0.0078 FL^{3.041}$

$r^2 = 0.984$



Hippoglossus stenolepis
(Pacific halibut)

Left otolith; length (mm): 12.8

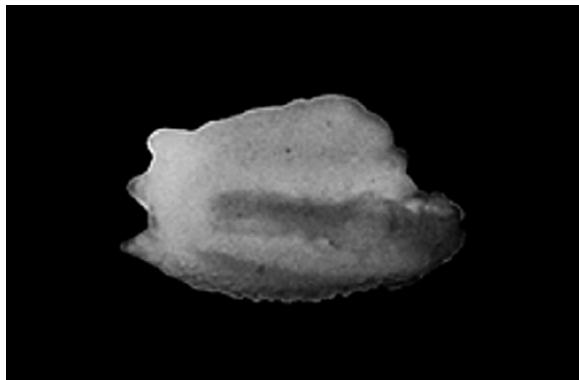
Fish length (cm): 80.0

Fish weight (g): 6,600.0

Regression equations:

Length: No data available

Weight: No data available



Hypsopsetta guttulata
(diamond turbot)

Left otolith; length (mm): 4.8

Fish length (cm): 21.3

Fish weight (g): 345.0

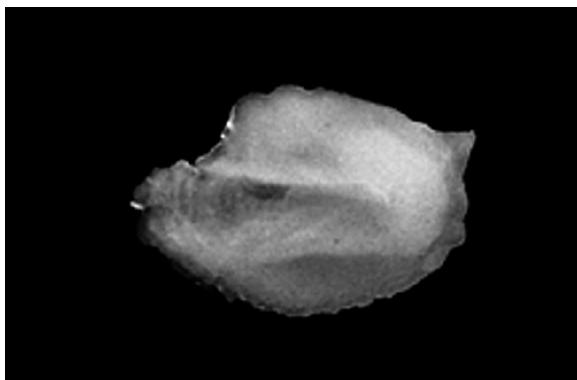
Regression equations:

Length: $SL = 4.89 (OL) - 0.29$

$r^2 = 0.835$

Weight: $WT = 0.0853 SL^{2.664}$

$r^2 = 0.967$

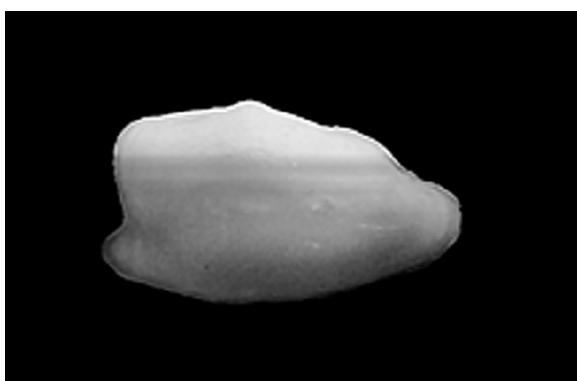
PLEURONECTIDAE (cont.)***Hypsopsetta guttulata*
(diamond turbot)**

Right otolith; length (mm): 4.7

Fish length (cm): 21.3

Fish weight (g): 345.0

Regression equations:

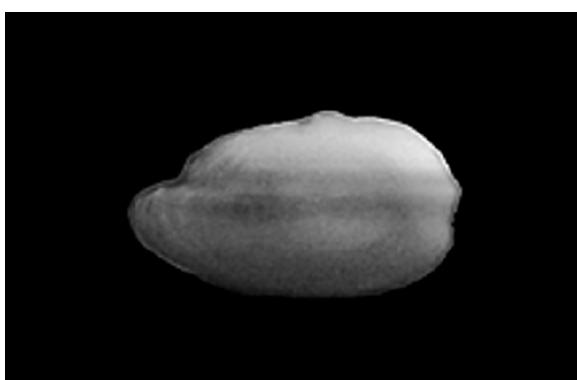
Length: $SL = 4.89 (OL) - 0.29$ $r^2 = 0.835$ **Weight:** $WT = 0.0853 SL^{2.664}$ $r^2 = 0.967$ ***Microstomus pacificus*
(Dover sole)**

Left otolith; length (mm): 5.3

Fish length (cm): 26.9

Fish weight (g): 268.1

Regression equations:

Length: $SL = 3.72 (OL) + 6.97$ $r^2 = 0.587$ **Weight:** $WT = 0.0094 SL^{3.092}$ $r^2 = 0.854$ ***Microstomus pacificus*
(Dover sole)**

Right otolith; length (mm): 5.4

Fish length (cm): 26.9

Fish weight (g): 268.1

Regression equations:

Length: $SL = 3.72 (OL) + 6.97$ $r^2 = 0.587$ **Weight:** $WT = 0.0094 SL^{3.092}$ $r^2 = 0.854$ ***Microstomus pacificus*
(Dover sole)**

Right otolith; length (mm): 4.6

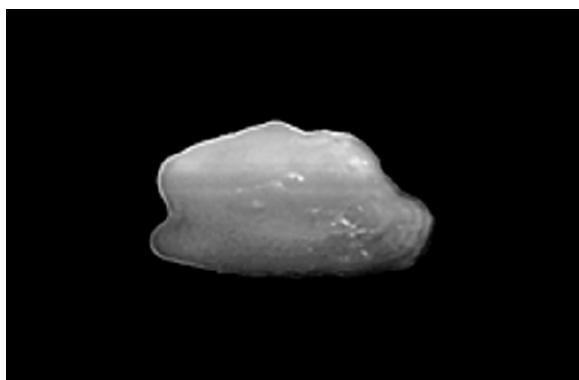
Fish length (cm): 26.2

Fish weight (g): 239.5

Regression equations:

Length: $SL = 3.72 (OL) + 6.97$ $r^2 = 0.587$ **Weight:** $WT = 0.0094 SL^{3.092}$ $r^2 = 0.854$

PLEURONECTIDAE (cont.)



Microstomus pacificus
(Dover sole)

Left otolith; length (mm): 4.8

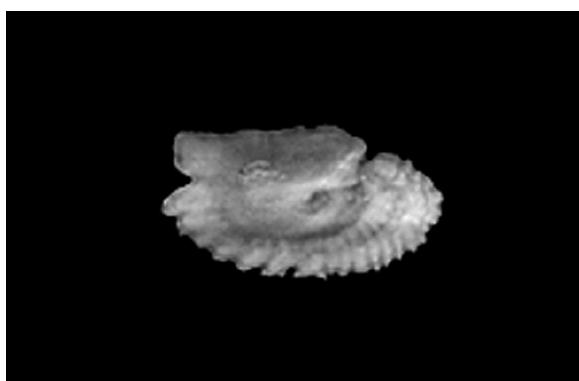
Fish length (cm): 26.7

Fish weight (g): 289.0

Regression equations:

Length: $SL = 3.72 (OL) + 6.97$ $r^2 = 0.587$

Weight: $WT = 0.0094 SL^{3.092}$ $r^2 = 0.854$



Platichthys stellatus
(starry flounder)

Left otolith; length (mm): 7.0

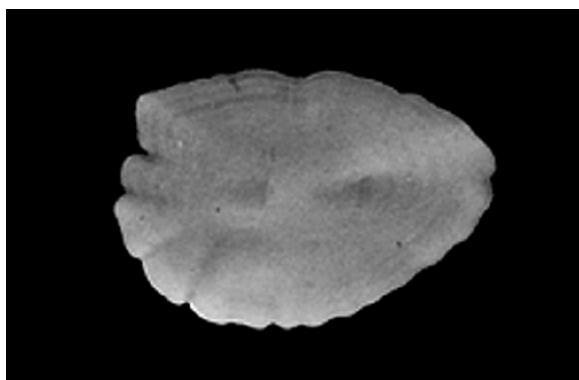
Fish length (cm): 27.6

Fish weight (g): 547.4

Regression equations:

Length: $SL = 3.35 (OL) + 0.23$ $r^2 = 0.814$

Weight: $WT = 0.0107 SL^{3.268}$ $r^2 = 0.985$



Pleuronectes asper
(yellowfin sole)

Left otolith; length (mm): 6.6

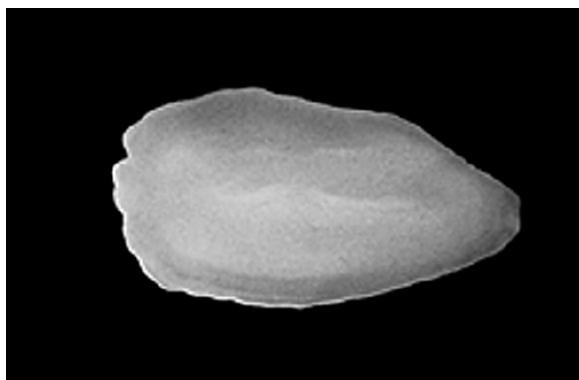
Fish length (cm): 25.3

Fish weight (g): 294.4

Regression equations:

Length: $SL = 2.17 (OL) + 10.65$ $r^2 = 0.638$

Weight: $WT = 0.0024 SL^{3.605}$ $r^2 = 0.859$



Pleuronectes bilineatus
(rock sole)

Left otolith; length (mm): 6.8

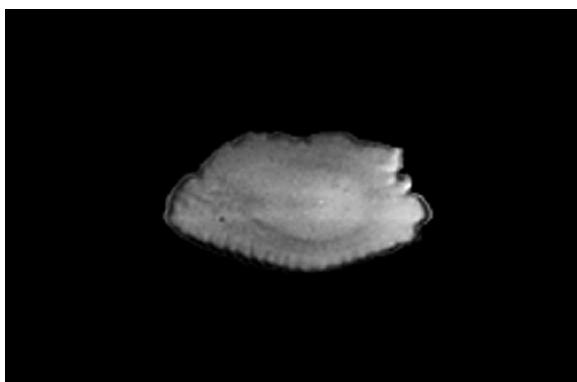
Fish length (cm): 23.5

Fish weight (g): 287.2

Regression equations:

Length: $FL = 6.16 (OL) - 6.97$ $r^2 = 0.841$

Weight: $WT = 0.0112 FL^{2.997}$ $r^2 = 0.931$

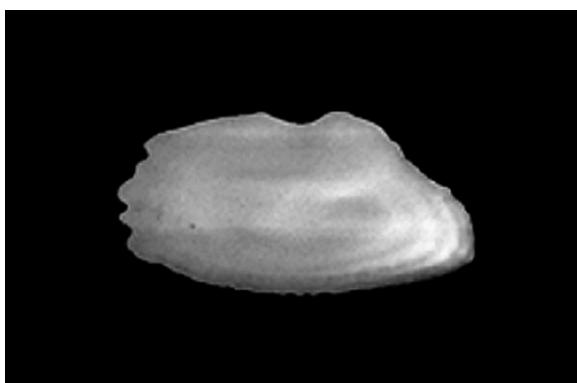
PLEURONECTIDAE (cont.)***Pleuronectes vetulus*
(English sole)**

Right otolith; length (mm): 6.6

Fish length (cm): 21.2

Fish weight (g): 104.0

Regression equations:

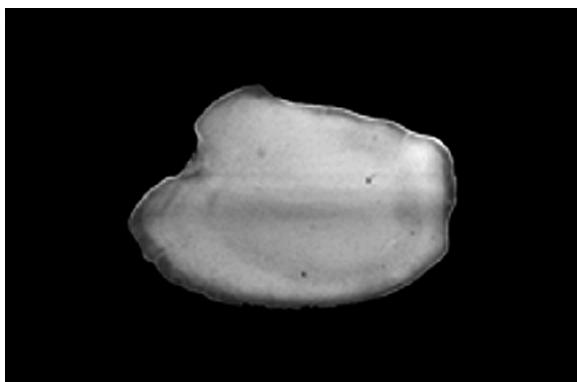
Length: $SL = 3.82 (OL) - 2.76$ $r^2 = 0.965$ **Weight:** $WT = 0.0163 SL^{2.939}$ $r^2 = 0.995$ ***Pleuronectes vetulus*
(English sole)**

Left otolith; length (mm): 9.0

Fish length (cm): 32.3

Fish weight (g): 439.2

Regression equations:

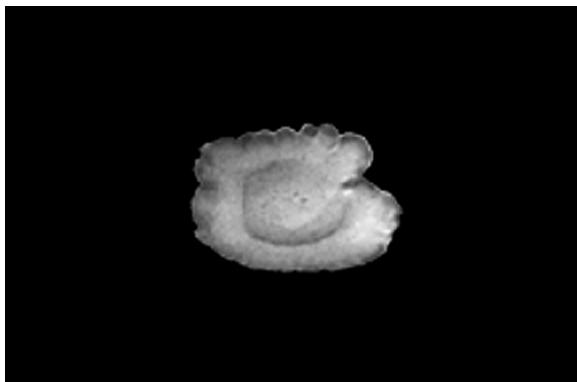
Length: $SL = 3.82 (OL) - 2.76$ $r^2 = 0.965$ **Weight:** $WT = 0.0163 SL^{2.939}$ $r^2 = 0.995$ ***Psettichthys melanostictus*
(sand sole)**

Right otolith; length (mm): 5.2

Fish length (cm): 23.0

Fish weight (g): 288.0

Regression equations:

Length: $SL = 5.06 (OL) - 3.18$ $r^2 = 0.942$ **Weight:** $WT = 0.0052 SL^{3.441}$ $r^2 = 0.983$ ***Psettichthys melanostictus*
(sand sole)**

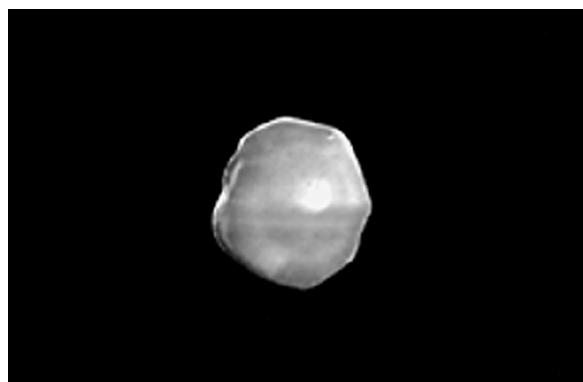
Left otolith; length (mm): 4.5

Fish length (cm): 21.7

Fish weight (g): 231.3

Regression equations:

Length: $SL = 5.06 (OL) - 3.18$ $r^2 = 0.942$ **Weight:** $WT = 0.0052 SL^{3.441}$ $r^2 = 0.983$

SOLEIDAE***Sympodus atricauda*
(California tonguefish)**

Left otolith; length (mm): 2.3

Fish length (cm): 14.5

Fish weight (g): 33.2

Regression equations:

Length: $SL = 3.56(OL) + 4.64$ $r^2 = 0.464$

Weight: $WT = 0.0074SL^{3.136}$ $r^2 = 0.789$